NORTH AMERICAN GUIDE TO NATURAL REFRIGERANTS IN ICE ARENAS

September 2022

ATMOsphere

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2022

ATMO Report

NORTH AMERICAN GUIDE TO **NATURAL REFRIGERANTS IN ICE ARENAS**

Originally published in August 2022.

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Executive Summary

This guide to natural refrigerants in North American ice rink arenas provides arena owners and managers with information on why refrigeration systems using a natural refrigerant – CO_2 or ammonia – are a better long-term choice from a business and environmental perspective than a system using an HFO blend like R513A or R449A.

Over the past few years, North American ice rink owners have been pressured by chemical producer Chemours and its marketing partner, the National Hockey League (NHL), to select HFO blend systems. What's most alarming is that the NHL and Chemours have promoted HFO blends as "environmentally sustainable" for ice rinks.

But HFO blends – consisting of an HFC and an HFO – represent a significant threat to the environment. By contrast, ammonia and CO_2 are found in nature and, as refrigerants, are environmentally benign. They are also more efficient and less costly than HFO blends.

Arena owners seeking to make a prudent investment in a refrigeration system need to consider the stark differences between natural refrigerants and HFO blends.

In the cooling and heating industries, CO_2 refrigeration is a very environmentally friendly option compared to f-gas refrigerants that have GWP values in the hundreds or thousands. Moreover, because it is benign to the environment, CO_2 can be considered a "future-proof" refrigerant, which will never be encumbered by the regulations that have targeted fluorinated refrigerants.

CO_2 is a very efficient refrigerant when compared with f-gases. Even in warm climates this is true when CO_2 systems are supplemented with technologies like adiabatic gas coolers, ejectors, parallel compression and subcooling.

Ammonia is one of the most common refrigerants used in ice arenas and other industrial applications in North America, with thousands of successful installations. Plentiful in nature, ammonia has no ozone depletion potential (ODP) and also no global warming potential (GWP = 0).

Ammonia has excellent thermodynamic properties, ensuring good energy efficiency performance, as well as abundance and low cost.

Ammonia's major drawback – toxicity – has been addressed through design features that minimize leaks, among other safety measures. The industry has also been focused on reducing the ammonia charge in systems to improve the safety of ammonia-based systems.

The first transcritical CO_2 system was installed in 2010 at Arena Marcel Dutil in St. Gédéon, Quebec, Canada. Built by CSC, this was a CO_2-only direct system, with the CO_2 delivered under the ice rink. Two years later, the first indirect CO_2 ice rink, with a secondary fluid under the ice, was installed at Dollard-Des-Ormeaux, Quebec, Canada.

By contrast to CO_2, ammonia has a long history of use in the ice rink industry in North America, particularly in Canada, where it has dominated. There are currently 2,860 ice rinks in Canada, 90% of which use ammonia systems that incorporate glycol or brine as a secondary refrigerant, with 3% using CO_2 systems.

In the U.S., there are 1,541 ice rinks, divided about equally between ammonia and f-gas (mostly R22) systems, with a handful of CO_2 rinks. More than 80% of ice rinks in California, the most populous U.S. state, use ammonia.

Notably, CO_2 refrigeration systems offer more waste heat for recovery and use for heating applications than any other refrigerant.

A study conducted by Canadian consultant Renteknik showed the superior energy performance of an ammonia system compared to a R513A system. The study, based on actual performance data collected over 10 days during March 2020, found a cooling efficiency of 0.74kW/TR and a heating efficiency of 19.65 EER for the ammonia system used at the Sports Center Jean Claude Tremblay, Arena 2, in La Baie, Quebec, Canada. By contrast, the study measured over the same time period a cooling efficiency of 1.29kW/TR and a heating efficiency of 12.54 EER for the R513A system, at another arena in the same vicinity, Centre Marius Sauvageau, in Chambord, Quebec, Canada.

While relatively new to the ice rink arena world, CO_2 is starting to be chosen as the refrigerant of choice by some high-profile entities. These include Nationwide Arena, the home of the Columbus Blue Jackets, which will be the first NHL arena to install a CO_2 system, and the National Speed Skating Oval (the Ice Ribbon) at the 2022 Beijing Olympics. Meanwhile, the Climate Pledge Arena, home to the NHL's Seattle Kraken, chose ammonia for a facility that is targeting net-zero-carbon certification by the International Living Future Institute (ILFI).

Federal and state/provincial regulations in North America affect the selection of ice rink refrigerants. Both the U.S. and Canada are phasing down HFC production and consumption in line with the Kigali Amendment, which will ultimately hamper the production of HFO blends and is already causing their prices to rise.

In Canada, a chiller (refrigeration or air-conditioning system that has a compressor, an evaporator and a secondary coolant, other than an absorption chiller) will not be allowed to use a refrigerant with a GWP greater than 750 as of January 1, 2025.

In the U.S., the Environmental Protection Agency will impose sector-based regulations at the federal level in 2023, based on feedback and discussions with stakeholders. One petition asked the agency to replicate at the federal level the ambitious HFC regulations established by the California Air Resources Board (CARB), including significant sector-based bans.

With regard to ice rinks installations, CARB mandates that, as of January 1, 2024, new ice rink facilities use a refrigerant with a GWP of less than 150 and existing facilities use one with a GWP of less than 750, .

The environmental impact of high GWP refrigerants on climate change and global warming is well known, and the reason HFCs are being phased down globally. What is not as well known is that HFCs' replacement chemicals, HFOs, while low in GWP, may also do significant environmental damage.

In particular, HFO-1234yf, which makes up 56% of R513A, when leaked into the atmosphere changes entirely into trifluoroacetic acid (TFA) in only 10–14 days. TFA then descends to Earth in rainfall.

While not currently regulated, TFA is potentially harmful to human health. It is accumulating in the environment, including in fresh water supplies from which it is extremely difficult to remove. The other component of R513A, R134a, also changes to TFA at a rate of 7 to 20%.

A Fact Sheet, "Choosing a Future-Proof Refrigerant for Your Ice Arena" – available here – summarizes the environmental and health issues raised by R513A.

Introduction

The ice that supports ice skating was once all produced via natural processes – outside, as pond water froze solid in the winter.

With the invention of refrigeration systems, the first indoor ice skating rink opened in London, England, in 1876. Under the rink was piped a mix of natural and synthetic compounds: glycerine, ether, nitrogen peroxide and water. Since then other synthetic substances have been employed in some ice rink systems, notably f-gases like R22.

The intent of this guide is to show that the ice used in ice rinks can and should be produced, as it was originally, using substances found in nature, specifically ammonia (NH_3) and carbon dioxide (CO_2).

As natural refrigerants, ammonia (R717) and CO_2 (R744) are not only environmentally benign (unlike their f-gas counterparts) but are also more efficient and less expensive than f-gases.

But the use of natural refrigerants in ice rinks has been increasingly challenged in recent years, as the chemical industry has stepped up its efforts to convert ice rink arenas to a new type of f-gas, HFO blends like R513A and R449A. These consist of HFCs in combination with HFO-1234yf, neither of which can be considered good for the environment.

The chemical producer Chemours and its marketing partner, the National Hockey League (NHL), are claiming that its HFO blends are "environmentally sustainable" for ice rinks. As Christina Starr, Senior Policy Analyst, Climate Campaign, for the Washington, D.C.-based Environmental Investigation Agency, explains in her opinion piece on page 12, this is a classic example of "greenwashing" – falsely attributing environmental benefits. Last year the EIA released a groundbreaking expose on the marketing relationship between the NHL and Chemours.

Ironically, many NHL teams remain committed to using ammonia as their ice rink refrigerant, and one team, the Columbus Blue Jackets, recently announced it has become the first NHL team to choose CO_2 as the refrigerant for Nationwide Arena, where it plays its home games. (See page 44.)

In this report, you will find many other examples of rinks using ammonia or CO_2 in their refrigeration systems, with significant operational benefits such as superior ice, energy efficiency, and heat reclaim for many heating applications.

You will also learn that ammonia and CO_2 systems are safe and effective options, contrary to the chemical industry's marketing claims. And you will find out about the growing evidence that one of the key ingredients of HFO blends – HFO-1234yf – is creating a new environmental issue, namely the formation of trifluoroacetic acid (TFA) in the atmosphere. TFA descends to Earth in rainfall and is accumulating in freshwater bodies, raising concerns about the safety of drinking water.

We hope this report will leave ice rink owners persuaded that natural refrigerant are the only refrigerants that make sense from a business, policy and environmental point of view, now and in the future.

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Acronyms/Abbreviations

AIM (American Innovation and Manufacturing) Act
ALT (alanine transaminase)
A1 (non-toxic, nonflammable)
A2L (non-toxic, mildly flammable)
A3 (non-toxic, flammable)
B2L (toxic, mildly flammable)
CARB (California Air Resources Board)
CCl_4 (carbon tetrachloride)
CO_2 (carbon dioxide)
COP (coefficient of performance)
DX (direct expansion)
EIA (Environmental Investigation Agency)
F-gas (fluorinated gas)
GWP (global warming potential)
HFO (hydrofluoroolefin)
HFO-1234yf (2,3,3,3-tetrafluoropropene)
HFC (hydrofluorocarbon)
kW (kilowatt)
kWh (kilowatt-hour)
LCC (Life Cycle Costing)
NH_3 (ammonia)
NHL (National Hockey League)
ODP (ozone-depleting potential)
OECD (Organisation for Economic Co-operation and Development)
PFAS (per-and polyfluoroalkyl substances)
POE (polyolester)
psig (pounds per square inch gauge)
R1234yf (2,3,3,3-tetrafluoropropene)
R125 (pentafluoroethane)
R134a (1,1,1,2-tetrafluoroethane)
R22 (chlorodifluoromethane)
R32 (difluoromethane)
R449A (blend of R32/24%, R125/25%, R134a/26% and R1234yf/25%)
R513A (blend of R134a/44% and R1234yf/56%)
R717 (ammonia)
R744 (CO_2)
SEI (system efficiency index)
TEWI (total equivalent warming impact)
TFA (trifluoroacetic acid or trifluoroacetate)
TR (tons of refrigeration)

Natural Refrigerant-Based Ice Rink Chillers

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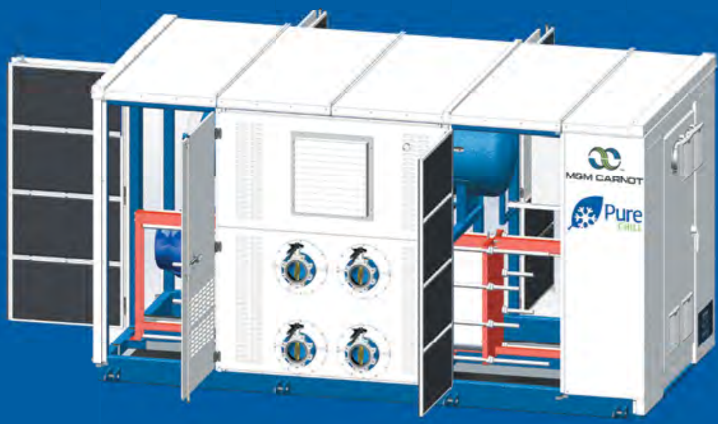

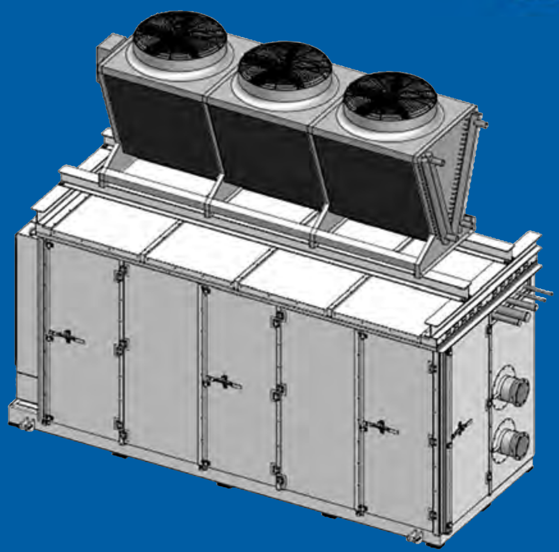

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- Ammonia Leak Detection and Built-In Ventilation

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We Must Stop Climate Misinformation, Including on Refrigerants

The NHL is misleadingly promoting Chemours' high-GWP HFC/ HFO refrigerant blends as "sustainable" for ice rinks, which has led to many replacements of a truly sustainable refrigerant – ammonia.

— By Christina Starr, Senior Policy Analyst, Environmental Investigation Agency

To meet the challenge of the climate emergency and prevent runaway warming tipping points, we need every tool, technology and solution available. Even more than that, we need true leadership, not just from politicians and governments, but from private institutions and companies.

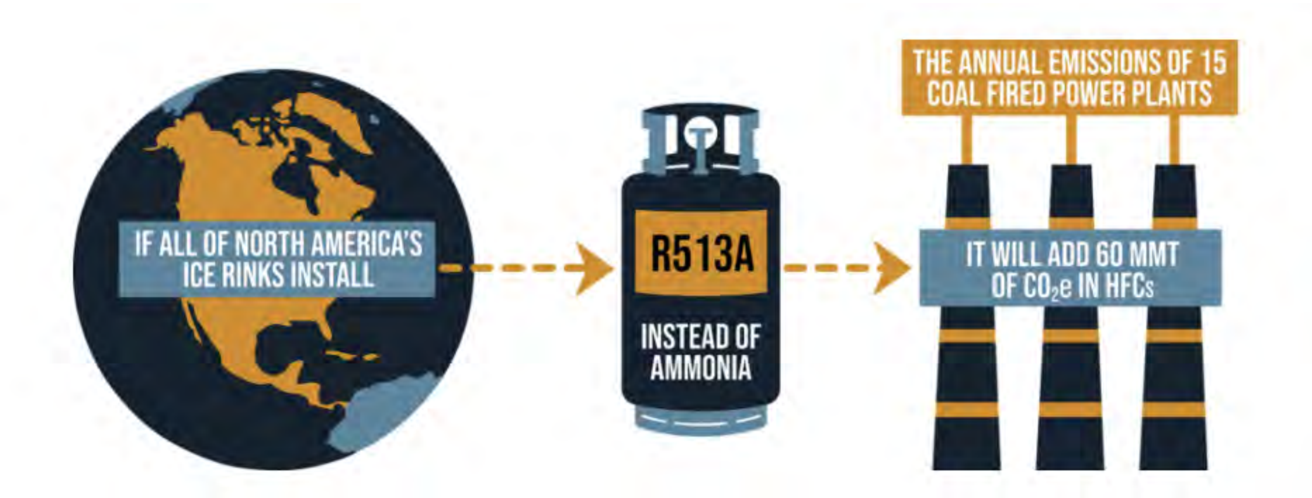
This is why misleading promotions about sustainability, false or unmet commitments, and greenwashing are so troubling. They give a mistaken sense that progress is taking place when it may not be, and in the worst cases, promote false "solutions" that can make the problem worse.

A case in point is the marketing partnership between chemical producer Chemours and the National Hockey League (NHL). It is alarming that the NHL is promoting Chemours' Opteon brand refrigerants R513A and R449A – HFC/HFO blends that are themselves super greenhouse gases – as "environmentally sustainable" for ice rinks.

The NHL is a household name synonymous with ice hockey, and its global influence and brand recognition extend far beyond the sport itself. The league, through its NHL Green program, partners with various organizations on sustainability initiatives in ice rinks. Yet, the NHL is promoting refrigerants from one company, Chemours, that have climate impacts hundreds or thousands of times worse than that of natural alternatives.

Various ice rink refrigeration experts confirm that ammonia, with a zero GWP, is widely used in existing ice rinks, and that CO_2 is another option. It is worrisome that the NHL's influence could actually lead to increasing high-GWP HFC emissions from ice rinks if ammonia systems are replaced by HFC/ HFO blends. As an NGO that uses investigations to expose the true nature of environmental problems, we decided to look into this further.

This led to "On Thin Ice," the Environmental Investigation Agency's report shedding light on the motivation, and the money, behind the NHL-Chemours partnership. I encourage you to read the report and watch the video for yourself, but here's an idea of the disturbing reality we uncovered.



Source: Environmental Investigation Agency

THE NHL: LIAISON FOR CHEMOURS

In recorded video conversations with EIA investigators, executives from the NHL and Chemours confirmed that the NHL agreed to accept about $2 million from Chemours to promote its Opteon refrigerants, R513A and R449A, as sustainable.

The NHL Green program itself and its leading sustainability experts play a major role in this promotional activity. In fact, a Chemours executive described the NHL sustainability team as a "liaison" between Chemours and NHL teams as well as the NHL's networks of community rinks; to that end, NHL executives do speaking engagements and attend trade shows and development discussions. The Chemours executive said of one NHL sustainability expert, "He comes along and is sort of the official representative of the NHL on our behalf."

INFLUENCING COMMUNITIES

The partnership seeks to leverage the brand and influence of the NHL, which has contractual milestones for converting a certain number of community rinks across North America to Opteon. In order to provide examples to community rinks, NHL staff helps persuade NHL teams to convert to Chemours' refrigerants. As the NHL executive acknowledged in the recorded conversations, "That carries weight with a lot of community rinks, right, when you have the NHL shield attached to your business card..."

Refrigerants are a technical subject and communities need independent experts to advise them on their options. The NHL also confirmed that it paid I.B. Storey Inc., an "independent" consultant who is the "official consultant of the NHL," to act "as an advocate on behalf of Chemours." Promotional case studies from I.B. Storey bearing the NHL's logo market Opteon R513A as a sustainable replacement for ammonia. It would be hard for communities to make an objective decision when being advised by an expert acting as a paid advocate for a certain company and refrigerant.

REPLACING ULTRA-LOW GWP REFRIGERANTS

The Chemours executive cited "double digits" of ammonia ice rink replacements with Opteon as a reason for their satisfaction with the NHL partnership. Even more alarmingly, he stated that the NHL partnership was helping Chemours to gain the trust of other new clients to branch out into sectors like industrial refrigeration where even more refrigerant is used.

Christina Starr, EIA

The need for climate leadership from organizations like the NHL has never been greater and we continue to urge them to step up their commitment to advocate and act on eliminating HFCs in ice rinks around the world.

EIA has estimated that if the thousands of community ice rinks across North America all converted to R513A instead of ammonia, it would lead to an additional lifetime emissions equivalent to 15 coal-fired power plants. The results could be far more disastrous for the climate, if Opteon refrigerants were to replace even a small share of the much larger quantity of ammonia refrigerant used in other sectors such as industrial refrigeration. It's clear that the NHL's partnership with Chemours could lead to much more HFC emissions, not less.

The response to our report has been overwhelmingly positive. Many members of the cooling industry have reached out to EIA thanking us for shedding light on the situation. The key facts uncovered in the report have not been contradicted, including the large agreed payment, and the potential widespread replacement of natural refrigerants in the sector by HFCs. In a response to the EIA, the NHL claims it never intended to encourage replacement of ammonia, though it does not directly deny that this could be a potential outcome. The need for climate leadership from organizations like the NHL has never been greater and we continue to urge them to step up their commitment to advocate and act on eliminating HFCs in ice rinks around the world.

We also hope regulators will consider our report's implications and pursue policies that limit replacement of ultra-low GWP solutions with HFCs in the sectors where non-HFC solutions are already widely adopted. It would be a step backward in our climate efforts if HFC systems with 20-year lifespans are permitted to replace technology already compatible with our ultimate climate goals.

Signs of the climate emergency are everywhere. Without rapid systemic action, we face catastrophic warming. Scientists say we must reach zero emissions by mid-century or risk passing thresholds above which it may be irreversible. Many areas of climate action will be challenging, requiring massive investment and even development of new technologies. We can't afford to delay, or take even one step backwards where true solutions are already in our grasp.

I encourage you to read EIA's report and take action by sharing a message with NHL leadership asking them to stop promoting HFCs at www.exposingclimatepollution.org.

1

Natural Refrigerants in North American Ice Rinks: Carbon Dioxide and Ammonia

1.1 CO_2 AS A REFRIGERANT

What is CO_2 refrigeration? And why is CO_2 a good thing when it comes to refrigeration? It is, after all, common knowledge that CO_2 emissions from fossil fuel consumption are one of the main drivers of climate change.

CO_2 — also called R744 when used as a refrigerant — and all other refrigerants used in air conditioning, heat pumps and refrigeration systems have been given a Global Warming Potential (GWP) value. The GWP explains the magnitude of its effects on the climate over a period of time, traditionally 100 years (though 20 years has been suggested as a more relevant time frame). As the main greenhouse gas, CO_2 has been given a GWP value of 1. This is to make comparisons between different refrigerants easier.

In the cooling and heating industries, CO_2 refrigeration is a very environmentally friendly option compared to synthetic refrigerants that have GWP values in the hundreds or thousands. Using CO_2 can actually help reduce the effect these industries have on the climate – significantly. And whatever CO_2 refrigerant escapes into the atmosphere can be easily sequestered by tree planting.

Moreover, because it is benign to the environment, CO_2 can be considered a “future-proof” refrigerant, which will never be encumbered by the regulations that have targeted fluorinated refrigerants. CO_2 refrigeration is now increasingly adopted by supermarkets around the world and is increasingly being used in ice rinks and other industrial sectors.

CO_2 is a very efficient refrigerant when compared with f-gases. Even in warm climates this is true when CO_2 systems are supplemented with technologies like adiabatic gas coolers, ejectors, parallel compression and subcooling. Many ice rinks limit use of refrigeration in warm climates by closing during the summer months, but even when operating year-round CO_2 systems perform efficiently.

1.2 AMMONIA AS A REFRIGERANT

One of the most common refrigerants used in ice arenas and other industrial applications in North America is the natural refrigerant ammonia, with thousands of successful installations. Plentiful in nature, ammonia has no ozone depletion potential (ODP) and also no global warming potential (GWP = 0).

Ammonia has excellent thermodynamic properties, ensuring good energy efficiency, as well as abundance and low cost.

Ammonia's major drawback – toxicity – has been addressed through design features that minimize leaks, among other safety measures. Nevertheless, a few major incidents have focused the industry on reducing the ammonia charge in systems as the most effective measure to improve the safety of ammonia-based systems.

In recent years the development of low-charge ammonia systems has taken center stage. Today a growing number of manufacturers offer systems that use less than 10lbs/TR (1.3kg/kW) of ammonia charge without compromising system efficiency, but actually further improving it.

1.3 HISTORY OF CO_2 AND AMMONIA IN THE ICE RINK INDUSTRY

CO_2 was first used as a refrigerant in the 19th century but fell out of favor with the development of f-gas refrigerants in the 1920s. It has been revived in the past three decades, thanks to the pioneering work in the 1980s by Norwegian scientist Gustav Lorentzen.

In the late 1990s, CO_2 began to be used as a secondary refrigerant in some European ice rink systems, pumped under the ice rink floor to freeze the ice, with ammonia typically employed as the primary refrigerant in the engine room.

Following the development of larger, higher-capacity CO_2 compressors, the first transcritical CO_2 system was installed in 2010 at Arena Marcel Dutil in St. Gédéon, Quebec, Canada. Built by CSC, this was a CO_2-only direct system, with the CO_2 delivered under the ice rink. Two years later, the first indirect CO_2 ice rink, using a secondary refrigerant under the ice, was installed at Dollard-Des-Ormeaux, Quebec, Canada.

In Europe, the first CO_2 ice rink system – a direct model – was installed in an arena in Gimo, Sweden, in 2014.

Following these installations, most CO_2 systems around the world have been indirect, employing CO_2 as the primary refrigerant, and glycol, brine or aqua ammonia (a 16–18% ammonia solution, commonly used in Europe) as the secondary refrigerant. Since most new CO_2 systems replace older systems in existing rinks, there is a tendency to want to reuse the plastic under-rink glycol or brine piping employed with the original system to reduce costs. Direct CO_2 systems require copper or stainless-steel piping.

What helped bring transcritical CO_2 refrigeration to ice rinks was its development in the supermarket sector in Europe and North America. In particular, the cost of components, and eventually the systems, decreased, and the number of compressors required dropped dramatically.

The use of ammonia as a refrigerant goes back 150 years, and it is the only refrigerant that has been continuously used throughout these years. By contrast to CO_2, ammonia has a long history of use in the ice rink industry in North America, particularly in Canada, where it has dominated.

There are 2,860 ice rinks in Canada, 90% of which use ammonia systems that incorporate glycol or brine as a secondary refrigerant, with 3% tilizing CO_2 systems.

Quebec's ice rink systems differ from the norm in Canada. Two decades ago, thety were split evenly between those using ammonia and those using R22 systems. Since then, following a major governmental subsidies program to replace R22 with other refrigerants, the ratio among Quebec's ice rinks is roughly one-third CO_2, one-third ammonia, and one-third an f-gas (often an HFO blend).

The reason why Quebec has a much lower percentage of ammonia ice rinks compared to the rest of the provinces in Canada is that it has the most stringent rules pertaining to operator oversight of ammonia systems. Elsewhere in Canada, the provincial rules for operators apply equally to all refrigerants, though some depend on the horsepower of the system, and they vary by the number of hours of operator duty per day.

Quebec's strict operator rules for ammonia – along with the generous subsidies provided by the government – have opened the door for the installation of CO_2 rinks in that province. Of the 86 CO_2 rinks in Canada, about 60 are in Quebec.

A new federal government program in Canada, launched in late 2021, supports the development of new and retrofit ice arenas with net-zero carbon emissions. Ice rinks are a focus of the program because they consume 20% to 30% of the energy in a typical municipality. The program is expected to bolster adoption of natural refrigerant-based ice rink systems over the next decade throughout the country.

In the U.S., there are 1,541 ice rinks, divided about equally between ammonia and f-gas (mostly R22) systems, with a handful of CO_2 rinks. More than 80% of ice rinks in California, the most populous U.S. state, use ammonia.

At the professional hockey level, 15 of the NHL's 32 rinks use ammonia-based refrigeration systems. In 2018, NHL players ranked the Bell Centre, home of the Montreal Canadiens, and Rogers Place, home to the Edmonton Oilers – both of which use ammonia systems – as first and second in ice rink quality, respectively. The Columbus (Ohio) Blue Jackets will begin using a CO_2-based system next year.

In Europe, there are as many as 80 CO_2 ice rinks, mostly in Northern Europe but some in Switzerland as well. About three-quarters use indirect CO_2 systems. Most new ice rink projects use CO_2, the rest employing ammonia. Historically, more than 95% of ice rinks in Europe have used ammonia, with very few employing f-gas systems.

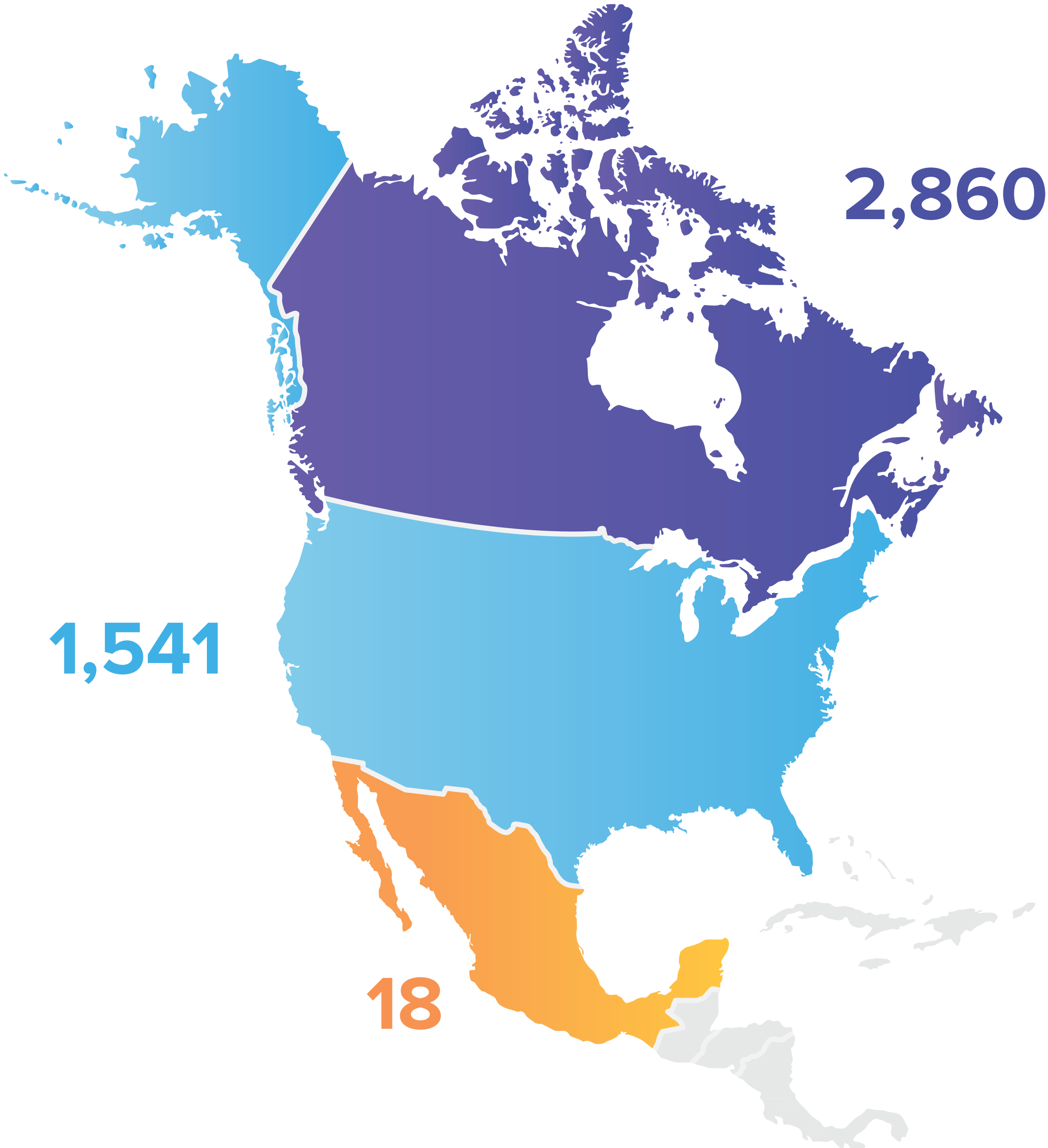
The prevalence of ammonia systems in the ice rink industry and in other industrial applications means that there is an ample supply of contractors and technicians familiar with maintaining and optimizing ammonia systems. Meanwhile, the growth of trans-critical CO_2 systems in the supermarket industry has increased the number of qualified CO_2 technicians, though there are far fewer of those than qualified ammonia technicians.

In general, the capital and servicing costs of CO_2 ice rink systems are less than those of ammonia systems.In North America, many regions have ammonia regulations that call for continuous on-site monitoring of ammonia systems.

1.4 Ice Rink Map of North America

North American Arenas

- Total number of rinks in US = 1,541
- Total number of rinks in Canada = 2,860
- Total number of rinks in Mexico = 18



Source for pages 19-22: CIMCO

Designed by ATMO sphere

1.5 Distribution of Refrigerants in North American Ice Rinks

- Ammonia installations
- F-gas installations*
- CO_2 installations
- Ammonia/CO_2 installations

Canada	USA	Mexico

Canada
- Ammonia = 90%
- F-gases = 7%
- CO_2 = 3%

USA
- Ammonia = 49%
- F-gases = 50%
- CO_2 = < 1%
- Ammonia/CO_2 = < 1%

Mexico
- Ammonia = 50%
- F-gases = 50%
- CO_2 = 0%

* R22, HFCs and HFC/HFO blends

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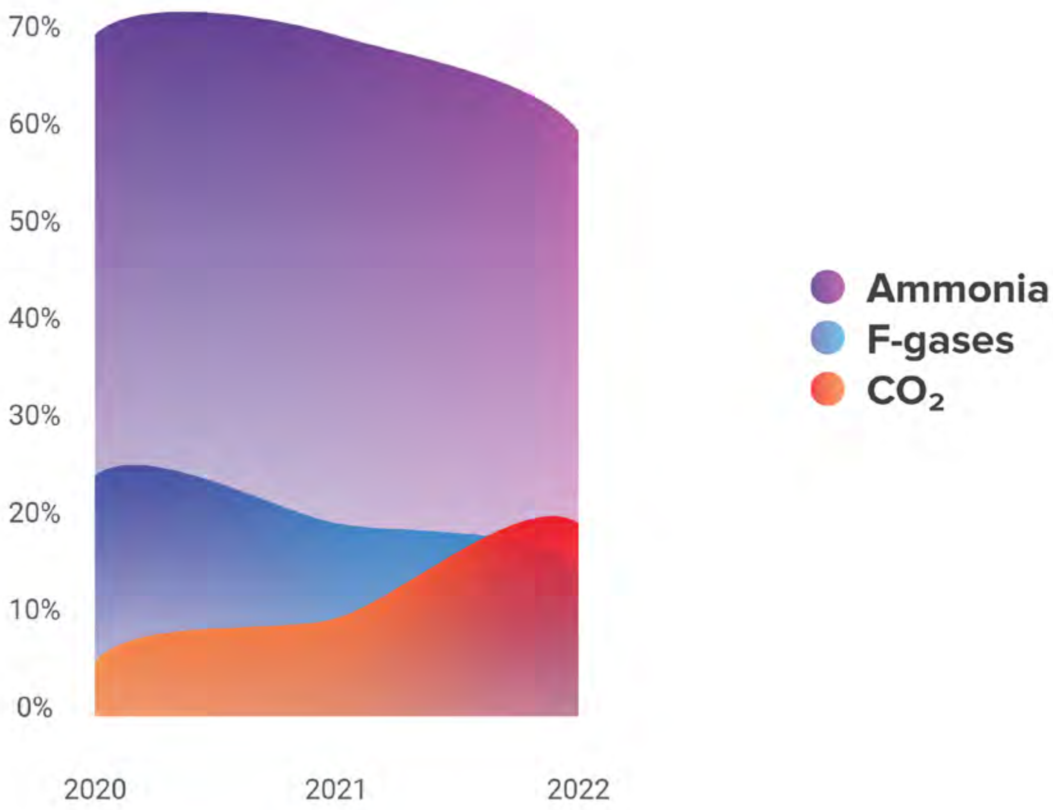
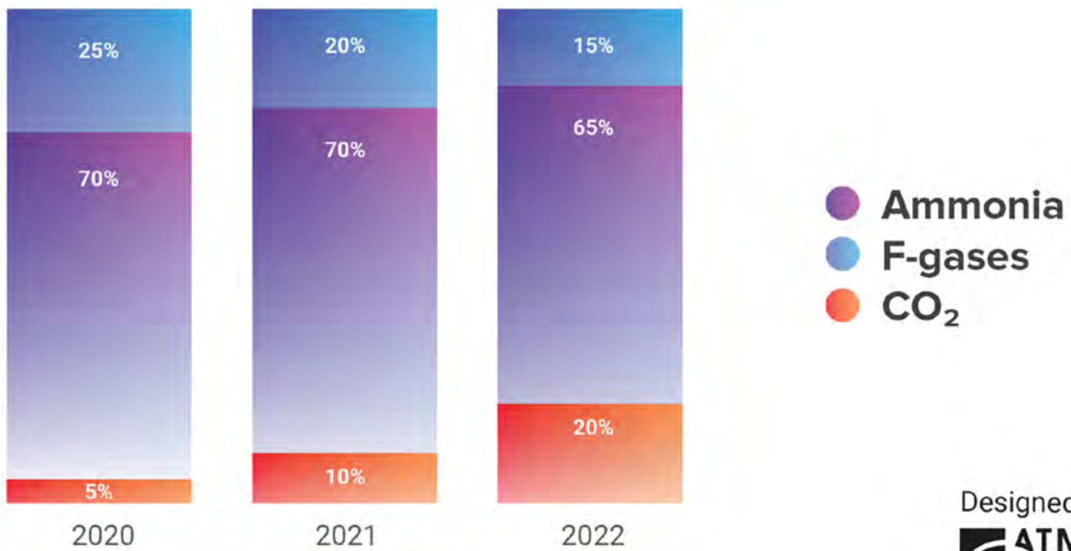
1.6 Evolution of Ice Rink Refrigerants in North America (2020-2022)

Percentage of new installations per refrigerant per year





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1.7 Natural Refrigerant Contractors

USA

- Alta Refrigeration
- American (Jacksonville)
- American Refrigeration
- APCCO
- APEX Refrigeration and Boiler
- ARS
- B.P. Mechanical Incorporated
- C and L Refrigeration
- Carlston-Stewart Refrigeration
- Catawba
- Colonial Webb
- Commercial Refrigeration MN
- DeVault (AKA colonial industrial)
- Devcon Mechanical
- Dual Temp
- Everything Ice PA
- Gartner Refrigeration
- General Refrigeration
- Generation Refrigeration
- Harris Refrigeration (Cape Breton)
- Hillbig / Brandt
- I.R.B.C
- Ice Builders NY
- Innovative Refrigeration
- J & J Air Conditioning & Refrigeration
- J.C.I.
- Jax
- JW Danforth
- Letso
- M&M Refrigeration
- Mantech Mechanical
- McNeil
- Mechanic Refrigeration Co
- Mericle Mechanical
- Mid West Refrigeration
- Minnesota Ice
- Mollenberg-Betz
- Mueller Inc
- North American
- Permacold
- Preston Refrigeration
- R.S.C.S
- RC and E
- RD&S
- RECCO/American Refrigeration
- Republic Refrigeration
- Rink Tec MN
- Serv-Ice MI
- Service Refrigeration
- SKMES
- Southeastern Refrigeration Inc
- Stellar
- Sterling
- Stone Mountain Mechanical
- Superior Boiler Works
- Superior Refrigeration
- TDI industries
- TDI Refrigeration
- Tempest Refrigeration
- Thermal Dynamics
- Total Mechanical
- TruTemp
- Uni-Temp Refrigeration, Inc.
- Wagner-Myner

Quebec

- Actair
- Aubin Pellisier
- BBG Refrigeration
- Corbus
- ForsAir
- Leprohon Inc
- Lesage
- LS Refrigeration
- Mauvalin
- Navada
- R&S Refrigeration
- Refri-Ozone
- Réfrigération Amesse
- Refrigeration Noel / QOB
- Réfrigération Nordic
- Réfrigération R3V
- Sd Bonair
- Technoref 4
- Zéro-C

Ontario

- A&D Mechanical
- AC Mechanical
- Ainsworth
- Ambient Mechanical
- Applied Systems Technologies Inc.
- Art Blake Refrigeration
- Berg Chilling Systems
- Besterd Mechanical
- Black and McDonald
- BML Multitrades
- Carrier Commercial Service
- CBS (Certified Building Systems)
- CES (Complete Energy solutions)
- Culliton
- Custom Ice Canada
- Drennan
- HECO
- Independent Supply Company

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- Carrier Commercial Service
- CBS (Certified Building Systems)
- CES (Complete Energy solutions)
- Culliton
- Custom Ice Canada
- Drennan
- HECO
- Independent Supply Company

Eastern Canada

- Acadia Refrigeration and Air Conditioning (1997) Limited
- Atlantica Mechanical Contractors Incorporated
- Birch Grove Refrigeration Limited (Cape Breton)
- Cabot Refrigeration
- Carmichael Engineering Limited
- Coldtech Refrigeration & Heating Inc.
- Conroy Refrigeration Limited
- Gil-Son Construction Limited
- Jamieson Electric & Refrigeration Ltd.
- Keep Cool Refrigeration & A/C Limited
- Kings Refrigeration & Air Conditioning
- Lowther Refrigeration Co LTD.
- Réfrigération Plus Inc
- Streamline Refrigeration Limited (Cape Breton)
- Valley Refrigeration & Air Conditioning Ltd.
- Young's Industrial Refrigeration Limited

Western Canada

- Accent Refrigeration
- Allweather
- Canada West Refrigeration
- Chinook Refrigeration
- Complete Climate Control
- Fraser Valley Refrigeration
- Gateway Mechanical Services
- Georgia Mechanical
- Georgia Strait Refrigeration
- Glacier Heights
- ICOM
- Independent Refrigeration Air Conditioning Inc
- Modern Energy
- Modern Niagara
- Norloc Refrigeration
- Northwest Refrigeration & Air Conditioning Ltd
- Paramount Services LTD
- Perfect Ice BC
- Prairie HVAC
- Precision Refrigeration
- Provincial Refrigeration
- Startec
- Stevenson Industrial Refrigera-tion
- Temp-Pro Refrigeration Ltd.
- Torque Mechanical
- Ultimate Fabrication
- Uptime Industrial
- Yeti Refrigeration

- Northwest Refrigeration & Air Conditioning Ltd
- Paramount Services LTD

2

Basics of Using CO_2 and Ammonia in Ice Arenas

2.1 CO_2 SYSTEM OPERATION

Typical refrigeration systems for rink applications operate subcritically, meaning that both the evaporation and condensation occur in the subcritical region, with temperatures below that of the refrigerant's critical point.

But due to CO_2's low critical point, which is 31°C (87.8°F) and 73.8bar (1,070.4psig), in warm ambient conditions it behaves not as a gas but as a supercritical fluid, expanding to fill its container like a gas but with a density like that of a liquid.

CO_2 refrigeration must therefore be designed for "transcritical" operation, which could be either subcritical or supercritical. In a transcritical system, evaporation (cooling) will always occur in the subcritical region; however, depending on ambient conditions, heat rejection could occur either subcritically (condensation) or in the supercritical region, where the condenser acts as a gas cooler instead of a condenser.

In high ambient conditions, the gas cooler will not condense the superheated CO_2 vapor to a liquid; instead it cools the supercritical fluid and rejects heat to the atmosphere. In cooler ambient conditions, the gas cooler does work like a condenser, converting the gas into a liquid. Often adiabatic gas coolers/condensers are used to improve the cooling process and the efficiency of the system. Other technologies that improve efficiency of CO_2 systems include ejectors, parallel compression and subcooling.

All components in a transcritical CO_2 system must be rated for higher working pressures, often using stainless steel.

The criticism that CO_2 systems are less efficient in warm climates has been effectively refuted by the use of equipment like adiabatic gas coolers, ejectors, parallel compression and subcooling, and emerging technologies like pressure exchangers.

Notably, CO_2 refrigeration systems offer more waste heat for recovery and use for heating applications than any other refrigerant. When CO_2's waste heat is fully utilized, it becomes the most efficient refrigerant for ice rink systems. In addition to providing heat for snow melting, under-floor heating, space/tap water heating, and even an adjoining swimming pool, recovered heat can be used for dehumidification, further cutting energy costs.

2.2 CO_2 REFRIGERATION: DIRECT FLOOR VS INDIRECT

In direct-floor (direct expansion/DX) CO_2 systems, CO_2 is used as the ice rink floor coolant. This is more costly than an indirect system using a secondary refrigerant. But a direct system is more efficient (requires less pumping energy, produces higher suction pressures), and, because it is easier to control, may produce better quality ice; this was evidenced at the Beijing 2022 Olympics National Speed Skating Oval (NSSO, aka the "Ice Ribbon"), where a new world record in speed skating and 10 new Olympic speed-skating records were set.

Direct systems can be more efficient than ammonia systems. When Concordia University in 2014 switched from an ammonia/glycol system to a direct CO_2 system, it saved 300kWh in the first five months.

With its larger charge of CO_2, direct CO_2 is more suited for larger arenas because of limits on the amount of CO_2 allowed to be released into the air in an arena's occupied space in North America. The ASHRAE-15 safety standard limits the amount of CO_2 to 3.6lbs/1000ft^3 of occupied space.

Indirect systems use glycol (propylene or ethylene), brine (calcium chloride) or aqua ammonia as the secondary coolant. These systems have lower capital costs and use less CO_2 than a direct system; but their efficiency is reduced becuase brine and especially glycol require more pumping power than CO_2 does. (Aqua ammonia can reduce indirect system costs by lowering the required pumping power for the secondary fluid.)

Moreover, there are also energy losses in an indirect system across the evaporator plates and less heat transfer on the rink floor itself. Brine also presents corrosion challenges, and may increase costs for CO_2 indirect systems by requiring titanium to be used in the evaporator.

But there are many examples of successful indirect CO_2 systems, which are the primary type of CO_2 system used in ice rinks. From a total cost of ownership perspective, direct and indirect CO_2 systems are comparable. Both direct and indirect CO_2 systems offer about the same amount of heat reclaim.

2.3 CO_2 SYSTEM DESIGN

CO_2 systems require pressure testing during installation, following piping standards. As there is a higher working and testing pressure, there will be a larger restricted distance, which generally requires more construction coordination.

CO_2 systems must be charged with vapor as liquid CO_2 will solidify during charging at pressures below the triple point (5.3bar/77psig and -57°C/-71°F).

Special CO_2 Valves

A transcritical CO_2 system has two more valves than an HFC system. They control the gas cooler and the intermediate pressure receiver, which collects liquid and gaseous CO_2.

The gas cooler pressure valve (also called the high-pressure regulating valve) controls the pressure in the gas cooler. It is a pressure-reducing valve, controlled by measuring two parameters – CO_2 pressure in the gas cooler and its exit temperature (exit/outlet of the gas cooler).

The receiver pressure valve (also called the medium-pressure regulating valve or the flash-gas valve) controls the pressure of the refrigerant in the receiver and associated liquid distribution. It is controlled by one parameter, the pressure in the receiver. The receiver is also called a flash tank.

The receiver separates the liquid phase from the vapor phase – the liquid is sent to the evaporator and the vapor is sent to the compressor.

Pressure Relief Valves

To minimize the risk of pressure buildup, measures must be taken in system design to ensure that pressure cannot build up in any portion of the system. All components, valves, piping, fittings, and joining methods must be verified to ensure pressure ratings above the maximum anticipated system pressures.

Pressure relief devices must be located appropriately to allow the system to vent safely in the event of a system shutdown or other event that causes pressures above system ratings. All points within the system must be allowed to vent back to the pressure relief valves without restriction. Check valves are typically utilized to allow portions of the system to vent back to receivers, where pressure relief valves are located. Any portion of the system that cannot vent back to the receiver must have its own pressure relief valve.

Stainless steel is currently the most used material and can be adapted for transcritical operation. Only the material thickness has to be adapted in order to resist high pressures. Alternatively, copper-iron alloy piping can be used with an appropriate pressure rating.

As the same system can operate in either subcritical or transcritical mode, depending on the conditions, higher quality piping needs to be used for all direct CO_2 systems.

CO_2 Evaporators

CO_2 gas is fed from the high-pressure receiver to the evaporators (either plate-and-frame or shell-and-tube) via an electronic expansion valve. In direct CO_2 applications, a brazed plate-and-frame heat exchanger is required because of the higher operating pressure. For indirect systems, glycol and carbon dioxide plates are more common in the market. For calcium chloride rinks, shell-and-tube heat exchangers are used.

CO_2 Compressors

Because CO_2 does not react with copper, semi-hermetic reciprocating compressors can be used, with motor windings in the housing.

Generally CO_2 compressors have a smaller capacity than ammonia compressors, so in a CO_2 system with the same load, you may see five to six compressors compared to two to three in an ammonia system. Oil management is essential for CO_2 systems, with different vendors having different designs.

Compressors need to be specifically developed for use with CO_2 to withstand high pressures and to be adapted to operating conditions that are sometimes very demanding.

Controls

Controls for a transcritical CO_2 system can be divided into four groups: gas cooler controls; receiver pressure controls; compressor capacity controls; and evaporator controls. In applications where heat reclaim is used, a number of control functions around the gas cooler have to be added.

An important aspect in controlling the gas cooler is that in transcritical mode, pressure and temperature are no longer dependent on each other. Thus, they need to be controlled individually.

Lubricants

Polyolester (POE) lubricants have good miscibility with CO_2 and are predominantly used as compressor lubricants in CO_2 systems. Because of the high solubility of CO_2, higher viscosity lubricants can be used when compared to those used with HFCs. This reduces the effect of oil dilution by the refrigerant and therefore maintains lubricant properties. POE oils are very hygroscopic (i.e., they readily absorb moisture), so care must be taken to ensure moisture does not enter the system.

Adiabatic gas cooler

Adiabatic gas coolers function like air-cooled gas coolers in mild ambients. But in high ambients, the adiabatic system uses running water over pre-cooling pads and draws air through the pads to cool the air, allowing for greater system heat rejection, thus improving overall system efficiency.

Adiabatic gas coolers are highly effective in hot, dry environments, using less water than traditional evaporative condensers.

Ejectors

Ejectors are being used to increase the efficiency of transcritical CO_2 systems, especially in regions with high ambient temperatures. Today, there are many different types of ejectors, which are often patented by specific manufacturers.

A typical ejector consists of a motive nozzle, a suction chamber, a mixing section, and a diffuser. In basic terms, an ejector is a way to re-use energy in the refrigeration system by not expanding the refrigerant but keeping its pressure relatively high. That is, the fluid coming out of the gas cooler is not expanded, so that the pressure can be kept high and less work is ultimately required for compression.

The gas in the suction line to the main compressor (at low pressure) and the fluid coming out of the gas cooler (at high pressure) are mixed in the ejector in order to get a mixed refrigerant at medium pressure.

More precisely, the primary flow is coming from the gas cooler, with the discharge pressure dependent on the ambient temperature, which can be relatively high. The secondary flow is coming from the suction line of the medium-temperature evaporator, with a relatively low pressure (because it has not yet been compressed). They are mixed to get the total flow. With this method, it is possible to increase the pressure of the total flow by a few bar, compared to the primary flow. Thus, the ejector is doing compressor work and creating a pressure lift.

In a concrete example, the evaporation temperature is -5°C (23°F), corresponding to 30bar (435psi). The gas cooler discharge pressure is 70bar (1,015psi) and thus the pressure of the total flow is 36bar (522psi), meaning that the ejector causes a pressure lift of 6bar (87psi).

Then, the flow goes into the receiver where the liquid is separated from the vapor phase; and the vapor goes into a parallel compressor or primary compressor.

Parallel compression

Parallel compression is a solution that compresses the excess gas at the highest possible pressure level. It leads to a significant increase of COP in warm climates.

Parallel compressors compress the flash gas coming out of the receiver, increasing it from receiver pressure to discharge pressure, which is higher than the suction pressure. A flash-gas valve would have sent the flash gas to the medium-temperature suction, dropping the pressure. Thus, parallel compressors make the flash gas valve obsolete for operation in high ambient temperatures. The energy savings occurs because the flash gas is compressed from a higher pressure than usual when a flash-gas valve is used.

2.4 BENEFITS/CHALLENGES OF CO_2 SYSTEMS

Benefits:

- Higher COP than f-gas systems, particularly if additional technologies are used.
- Future-proof against regulations.
- Environmentally friendly, important to consumers.
- Space saving compared to ammonia, with smaller pipes, compressors and other equipment.
- The availability of high-grade heat. While only 15% of an ammonia compressor's discharge heat can be rejected to building loops at 26–30°C (80–85°F), all of the gas cooling process of the transcritical system can be used to produce 60°C (140°F) hot water. However, 100% heat reclaim will make the refrigeration cycle less efficient due to greater flash-gas generation.

Challenges:

- Training of technicians, though more technicians are becoming skilled in CO_2 via experience in supermarkets.
- Higher pressures, though all equipment is rated for these pressures.
- Oil management, though ample equipment is available.
- CO_2 reacts with water to form carbonic acid. Thus systems require filter driers as water migrates to the coldest part of the loop (the evaporator). Carbonic acid may interact with carbon steel to hasten corrosion, and embrittlement of carbon steel at low temperatures is possible, so stainless-steel or copper piping is recommended.
- Efficiency in warm climates, which is a non-issue with the application of technologies like adiabatic gas coolers, ejectors, parallel compression and subcooling.

2.5 CO_2 SAFETY

As an A1 refrigerant, CO_2 is considered to have low toxicity and low flammability. But a large leak of CO_2 can displace existing air in a space, reducing the oxygen levels. If the oxygen levels are reduced considerably, this can lead to health hazards up to and including asphyxiation.

Average outdoor air consists of around 400ppm of CO_2, or 0.04%. The Occupational Safety and Health Administration (OSHA) has set the permissible exposure limit of 5,000ppm (0.5%) for eight hours per day (compared to 1000ppm for most HFCs).

Another issue is the amount of CO_2 that is allowed to enter the arena space; the ASHRAE-15 safety standard limits the amount of CO_2 to 3.6lbs/1,000ft^3 of occupied space. (Previously, the limit was 5.5lbs/1,000ft^3.) In CO_2 systems that use a secondary refrigerant for the ice rink, the charge limit is basically a non-issue. Even for CO_2-only systems, it is of minimal concern, given the use of stainless steel piping under the rink. However, these limits have resulted in many more indirect CO_2 systems being installed, particularly in smaller rinks.

The primary safety issue associated with CO_2 systems is the higher pressures that have to be accommodated, up to 1,750psig. This requires the "high side" of the CO_2 system to be constructed using higher pressure rated materials and installation practices, at a higher cost. To reduce overall system installed cost, the "low side" portions of a CO_2 system are designed for the lower operating pressures, allowing copper to be used for the low-side piping. When the system is operating normally, pressures are maintained below the rated pressure of the system.

While often portrayed by f-gas producers as a danger, the pressures are easily maintained with stainless-steel piping and tig-welding techniques. HFO systems at 250psig are no less safe if there is a catastrophic leak, which may be more possible if inexpensive "soft" copper piping is employed.

2.6 AMMONIA SYSTEM OPERATION

Ice rink systems that use ammonia as the primary refrigerant use a secondary refrigerant, usually glycol or brine in North America, in the rink floor to remove heat from the ice rink. As the secondary refrigerant is pumped through the rink floor, it absorbs heat, and is transported back to the evaporator. There, heat is transferred from the glycol or brine to ammonia through either a plate-and-frame or shell-and-tube evaporator.

Once the ammonia is evaporated, the vapor is drawn to the compressor to change low-pressure vapor to high-pressure vapor. The work in the compressor is what allows for the movement of heat. A larger difference between evaporating temperature and condensing temperature will require more work.

From the compressors, the high-pressure, high-temperature vapor goes to the condenser, where it is condensed to a high-temperature, high-pressure liquid by heat rejection. Heat can be rejected to the ambient air by evaporative or adiabatic condensers or recovered in a heating loop used to heat a building, for example.

Once condensed, the high-pressure liquid refrigerant passes through an expansion device (such as a float valve or an electronic control valves), dropping the pressure and temperature of the refrigerant, which is now a low-temperature, low-pressure liquid.

In the design of flooded plate-and-frame or shell-and-tube evaporators, the evaporating liquid will produce a temperature differential in the secondary refrigerant. In refrigerant direct expansion (DX) systems, the refrigerant is controlled by an expansion valve to maintain a set saturated suction temperature and superheat.

2.7 AMMONIA SYSTEM DESIGN

For any ammonia ice rink system, there are many design options. The equipment decision will be a based on rink conditions, budget, desired efficiencies, and, ultimately, customer preference.

Ammonia Evaporator

For the chiller's evaporator in a secondary ammonia system, the typical arrangement is to use a plate-and-frame or shell-and-tube heat exchanger, either flooded or DX.

For a lower charge of ammonia, a plate-and-frame heat exchanger is recommended, and an even further reduction in refrigerant charge is found with a DX system. Plate-and-frame heat exchangers for rink applications are semi-welded designs, which have welded cassettes on the ammonia side, and gasketed on the brine side, all secured with a frame. The gaskets need regular replacement (every five-10 years, depending on wear), but can be maintained and repaired in place.

The design of these heat exchangers also allows for future capacity increases, via the addition of plates to the chiller. With glycol as the secondary fluid, aluminum or steel plates can be used in the evaporator; with calcium chloride brine, titanium plates (which are more expensive) will be needed.

Shell-and-tube heat exchangers have tube bundles where the secondary refrigerant flows, and then a vessel containing the ammonia. With the larger tube volume, there is a lower pressure drop through the chiller compared to plate-and-frame evaporators. This is useful for secondary refrigerants with a higher level of particulates.

Shell-and-tube heat exchangers do require a larger ammonia charge, and a larger footprint in the engine room. There is less maintenance than for a plate-and- frame heat exchanger, though generally the whole shell-and-tube unit needs to be replaced at the end of life. If there is a leak in a specific tube bundle, these can be plugged, but that will reduce the capacity of the heat exchanger.

Ammonia Compressors

For ammonia applications, either reciprocating or screw compressors can be used. These are both positive displacement compressors that reduce the volume of a compression chamber through mechanical work, thereby increasing the pressure of the refrigerant.

Reciprocating compressors often have the lowest first cost, but require more frequent maintenance. They have a crankshaft, pistons, and cylinders, with other moving parts such as valves and connecting rods.

Reciprocating compressors use discrete steps (banks of cylinders) in part loading, which, depending on the system design, can be ideal for partial loads. Another feature is limited maximum pressure differential. Reciprocating compressors use either belt drive or direct drive.

In belt-driven systems, a belt is run from a wheel on the motor to another wheel on the compressor, increasing torque and decreasing vibration transfer. In direct drive, the compressor's crankshaft is connected directly to the motor, which means the compressor will spin at the motor's speed, making it more efficient than with belt drive. The drawback for direct drive is that vibrations in the compressor will transfer to the motor and can cause greater wear and tear. Direct-drive compressors may also require a large base/foundation.

Reciprocating compressors generally are more efficient than screw compressors, with a larger COP. Also, both unloading and a variable-frequency drive (VFD) can be used concurrently with reciprocating compressors, allowing for greater part-load efficiency.

Screw compressors are a rotary machine with two rotors. Gas passing through the suction port is led to the space between the meshing lobes of the rotors. As the rotors turn, this space is reduced, compressing the vapor.

Screw compressors tend to have a higher first cost, but a lower maintenance cost, with fewer moving parts. There is a higher allowable pressure ratio than with reciprocating compressors.

Partial loading with screw compressors can be discrete or continuous with slide valves and VFD speed control. However, screw compressor slide valves must be fully loaded if VFDs are used for capacity control. This means there is less part-load capacity compared to a reciprocating compressor of a similar size.

To seal the rotors and lubricate bearings in screw compressors, large amounts of oil are required, which means there must be attention to the design of the oil cooling circuit for screw compressors.

Ammonia Condensers

Many types of condensers can be used in an ammonia system. A traditional method would involve evaporative condensers, with an ammonia coil outside, and water used in the condenser. An alternative would be a cooling tower, with a heat exchanger on the ice rink system to reduce the ammonia charge. Fluid coolers can also be used, often with the secondary refrigerant tied into a building heating loop.

Any type of evaporative condenser or cooling tower will require a water tank, either mounted on the condenser or with a remote sump. In colder climates, remote sumps are generally recommended to prevent the likelihood of condenser freeze-ups. These systems will also require some form of water treatment and passivation, adding cost to the system.

A newer technology, especially useful in cold climates, is an adiabatic condenser, which reduces water use. Adiabatic condensers don't require water pumps or tanks, reducing cost. Dry coolers can also be used, so that the water requirements are removed, but dry coolers and condensers require a larger footprint than evaporative or adiabatic condensers do.

Ammonia Expansion Valves

For ammonia to change from a high-pressure liquid to a low-pressure, low-temperature liquid, it has to pass through an expansion valve. This valve can be mechanical only or controlled electronically. Systems can be overfeed, or direct expansion (DX), depending on the design.

A mechanical float valve is used on systems with some overfeed. It operates through gravity – as the liquid in the condenser accumulates, pressure acts on the valve, opening it and allowing ammonia to expand into the low-pressure side.

DX systems are regulated with either a thermostatic expansion valve or an electronic superheat controller.

Some flooded systems are designed with electronic expansion valves, which regulate liquid feed based on level.

2.8 BENEFITS/CHALLENGES OF AMMONIA SYSTEMS

BENEFITS

- Natural refrigerant, zero GWP, zero ODP.
- Availability of experienced refrigeration technicians.
- Large number of installations.
- Availability of parts.
- Many design options, all with CRN/NB number.
    - CRN (Canadian Registration Number) is required for pressure piping equipment by the local authority having jurisdiction; this is needed for a pressure piping registration as part of the installation process.
    - NB (National Board) number is the American equivalent.
- Greater efficiency than HFO blends.
- Improved safety designs, including low-charge systems.
- Ammonia's odor is very noticeable in small quantities, alerting personnel to leave the machine room.

Challenges

- B2L classification as per ASHRAE 34 – toxicity, low flammability.
- Design requirements for safety and oil management.
- Higher local requirements (Class T engine room, operator supervision, for example)
- Copper piping can't be used due to incompatibility with ammonia

2.9 AMMONIA SAFETY

Notwithstanding the unfortunate accident at an ice rink in Fernie, B.C., Canada in 2017, where three technicians were killed by an ammonia release, ammonia accidents in the rink industry are exceedingly rare. The Fernie system, which was not maintained properly and thus much more vulnerable to a deadly leak, was an outlier.

Still, manufacturers have been making ammonia rink systems safer in a variety of ways:

- Systems are designed with great care and quality control, and are thoroughly pressurized and welded.
- Systems can be charged with much less ammonia. A 15,000-seat arena that previously used 1,800lbs (817kg) of ammonia can now use 150–200lbs (68–91kg).
- Ammonia gas detectors should be used throughout the machine room, with competent people operating the system.
- Relief systems: Any pressure vessel or system where ammonia can be trapped requires a relief device, sized per code requirements.
- Regular maintenance – such as for oil changes, equipment inspection, fluid analysis – is required on all ammonia systems.

2.10 AMMONIA/CO_2 CASCADE SYSTEMS

Using CO_2 as the secondary fluid – as opposed to glycol or brine – reduces pumping power by 25%, though this requires a steel floor rated for higher working pressures. In addition, boiling CO_2 is a more efficient method of heat transfer than the convection with glycol or brine as the secondary refrigerant.

There are not many example of this in North America, as there is a significant first cost for the CO_2 floor. One example is at the University of Anchorage, in Alaska.

One caveat is the need to prevent mixing of CO_2 and ammonia in the heat exchanger. This would form ammonium carbonate, which is corrosive and would clog the system.

2.11 AUTOMATION

Most ice rink systems contain at least some automated controls, for basics such as thermostats and timers, or run on a fully automated programmable system. Many automated systems have graphic displays that can connect to computers or mobile devices for remote monitoring and system control.

Automation systems can be used to increase the efficiency of an ice rink system through:

- Floating head pressure controls, taking advantage of colder ambient temperature to reduce the compression ratio.
- Reducing the speed of fans to reduce power consumption.
- Changing the timing on staging of compressors, condensers, etc.
- Cycling equipment for equalized operation time, which is very useful if there is standby equipment.
- Monitoring temperature/pressure trends over time.
- Demand limiting, such as limiting a three-compressor system to two compressors when time-of-use energy billing applies.

Automation systems increase safety in a variety of ways:

- Remote operator actions, such as turning off equipment and changing set points.
- Automatic alarm systems that can alert operators.
- Monitoring system conditions and recording history of alarms, events, etc.

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2.12 COMPARISON OF EFFICIENCY AND COSTS OF AMMONIA, CO_2 AND HFO BLENDS

Ice rink operators interested in simulating the energy usage of ice rink systems using different refrigerants can employ Denmark's Pack Calculation Pro, available for free download here.

Pack Calculation Pro calculates yearly energy consumption, as well as Life Cycle Costing (LCC) and Total Equivalent Warming Impact (TEWI).

The software uses load profiles and weather data to calculate performance, including "well-proven default values for most coefficients and parameters," though operators can import their own load profile data.

Meanwhile, a number of independent studies have been done showing the energy advantages of CO_2 and ammonia ice rink systems.

Canadian Chiller Study Finds Ammonia Outperforms R513A in Cooling and Heating Efficiency

In a 2020 study of two Canadian ice rinks arenas, the arena using an ammonia/NH_3 (R717)-based chiller system performed significantly better in both cooling and heating efficiency than a chiller system employing R513A, an HFC/HFO blend (44% R134a and 56% R1234y).

The study was conducted by Renteknik Group, an energy consulting firm based in Burlington, Ontario, Canada. The study is available for free viewing and download here.

The study, based on actual performance data collected over 10 days during March 2020, found a cooling efficiency of 0.74kW/TR and a heating efficiency of 19.65 EER at the Sports Center Jean Claude Tremblay, Arena 2, in La Baie, Quebec, Canada. By contrast, the study measured over the same time period a cooling efficiency of 1.29kW/TR and a heating efficiency of 12.54 EER, at another arena in the same vicinity, Centre Marius Sauvageau, in Chambord, Quebec, Canada. The arenas are 100km (62mi) from each other.

Both chillers use glycol as the secondary coolant for the ice rinks and glycol heat reclaim for space and domestic water heating.

Energy Comparison of R717 and R513 Ice Rinks

Arena Name	Average Cooling Energy Delivered	Average Cooling Efficiency	Average Heating Energy Delivered	Average Heating Efficiency
Sports Center Jean Claude Tremblay Arena 2 (NH_3)	93.16TR	0.74 kW/TR	111.12TR	19.65 EER
Centre Marius Sauvageau (R513A)	39.66TR	1.29 kW/TR	53.22TR	12.54 EER

Source: Renteknik Group


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The performance data was collected utilizing a proprietary ClimaCheck Performance Analyzer. The analysis was independent of input from the system or component suppliers.

In order to compare the systems, the following metrics were measured:

- Suction Pressure
- Suction Temperature
- Discharge Pressure
- Discharge Temperature
- Liquid-Line Temperature
- Compressor-Discharge Temperature
- Heat-Reclaim Supply Temperature
- Heat-Reclaim Return Temperature
- Power Consumption

The following operational parameters were measured:

- Refrigeration Capacity
- Condenser/Heating Capacity
- Heat Reclaim Performance
- kW/TR and COP rating
- Refrigeration Cycle Isentropic Efficiency
- System Efficiency Index (SEI)

The refrigeration system at Arena 2 in the Sports Centre Jean Claude Tremblay utilizes a traditional ammonia refrigeration cycle. It consists of four compressors, two heat-recovery heat exchangers servicing space heating and the domestic hot water (DHW), as well as a cooling tower when space heating within the building is not required or when additional heat rejection is needed.

The R513A refrigeration system at the Centre Marius Sauvageau utilizes a dual-circuit chiller, with one compressor per circuit.

R744 Delivers Low Operating Costs in U.S. Ice Rink Chiller Study

In a study of packaged chiller systems used for ice rinks, a transcritical CO_2 chiller was found to deliver a payback on its cost premium over a baseline system in "a few years," based on 13%–33% lower operating (electricity and water) costs.

The study – "Analysis of Package Chiller Systems – Comparison of Natural (NH_3 and CO_2) and HFC Refrigerants" – was conducted by John Collins, Industrial Sales Manager, Zero Zone, whose Refrigeration Division is based in Ramsey, Minnesota (U.S.). Released in 2020, the study is available for purchase here.

The paper compares CO_2 and NH_3 chiller systems with two chillers using the HFO blend R448A; one of the R448A chillers employs evaporative condensing (the baseline system), and one is air-cooled. The chillers all use circulated glycol coolant. The nominal refrigeration capacity of the chillers is 160TR (562kW).

The energy analysis in the paper is based on "calculated performance" derived from "readily available manufacturer data on component performance over the range of operating conditions," the paper said. In particular, performance data was taken from "Bitzer compression selection software and other published equipment data on the heat exchangers and condensers/gas coolers," Collins said.

The analysis of water consumption is based on a nominal 0.30gal/TRh (0.32ltr/kWh) for the evaporative condenser systems (baseline and ammonia), and one-quarter of this rate for the adiabatic gas cooler (in the CO_2 system).

"This is a comparative analysis to show relative performance of the considered options across a range of operating conditions," Collins said. "The performance data is not intended to serve as an annual or life cycle cost analysis."

While the costs of transcritical CO_2 chillers are declining, the installed cost of the CO_2 system in the study was 47% higher than that of the baseline unit, the paper noted. The installed cost of the ammonia chiller was 67% above that of the baseline system.

The overall performance of the CO_2 chiller, including energy and water usage, "allows for payback of the 47% premium in first cost over the baseline in just a few years," the paper says. On the other hand, the 67% premium for the ammonia system "will take several years to make up."

In the study, the chillers were evaluated based on climates in four U.S. cities, Minneapolis, Minnesota (cold northern climate); Philadelphia, Pennsylvania (mixed humid northern); Atlanta, Georgia (mixed humid southern); and Los Angeles, California (dry warm). They were analyzed at 100% load, 55% load and for seasonal operation (September–April).

The CO_2 chiller employs parallel compression and adiabatic condensing, enabling it to "perform effectively at each of the locations considered over the entire range of annual weather conditions," the paper says.

Compared to the baseline system, the CO_2 chiller used less energy in the majority of the annual operating hours (62% of annual hours in Atlanta and 83% of annual hours in Minneapolis and Los Angeles). The added electric cost for the limited number of hours of peak hot weather operation "is more than offset by the savings during off-peak operation," the paper says. Moreover, since the systems operate at reduced capacity much of the year, this "further improves the overall electric savings for CO_2 over the baseline system."

The electrical savings for the CO_2 system, combined with much lower water use for the adiabatic gas cooler/condenser, "results in the total operating costs between 13% and 33% below baseline across the range of locations and conditions," the paper says.

The electric use/cost of the ammonia system is the least for all the options, but the added cost of water for evaporative condensing "more than offsets the electric savings," says the paper. "This is more pronounced in cooler climates and where water costs are high."

Swedish Study: Heat Recovery Boosts Energy Performance of CO_2 Ice Rinks

A 2019 study conducted by EKA (Energi & Kylanalys) compared the energy performance of five ice rinks in Sweden retrofitted from conventional refrigeration systems (HFC and ammonia) to transcritical CO_2 (direct and indirect) with optimized heat recovery.

Field measurements showed that the operational energy use could be cut by 18 to 55%, with some rinks becoming self-sufficient by using their own recovered heat, eliminating the need for an external heating system and allowing for the export of excess heat to a nearby facility.

2.13 ICE RINK SYSTEM CHECKLIST

CO_2 Transcritical

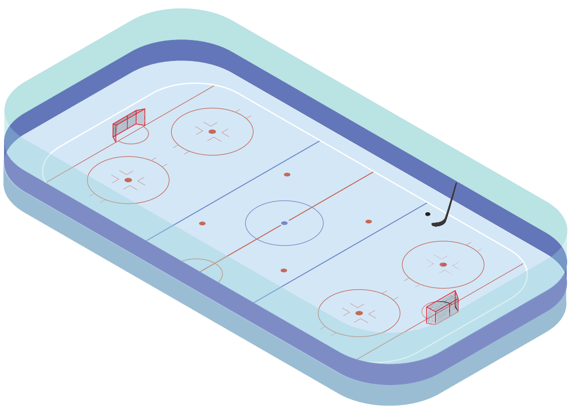
- Future-proof against phase down
- Part of nature
- GWP = 1
- High-grade heat reclaim
- Higher pressures easily managed
- Direct (CO_2 under ice) or secondary (glycol, brine or aqua ammonia under ice)
- 13–33% less operating costs (energy and water) than R448 chiller with evaporative condenser*

Ammonia Chiller

- Future-proof against phase down
- Part of nature
- GWP = zero
- Heat reclaim
- Self-alarming
- Large number of installations
- Low charge available
- Safe when properly maintained
- 0.74 kW/TR average cooling efficiency vs 1.29 kW/TR for R513A chiller**
- 19.65 EER heating efficiency vs. 12.54 EER for R513A chiller**

HFO Blend Chiller

- HFC component being phased down
- HFO component forms acid rain (TFA)
- Not part of nature
- High GWP compared to natural refrigerants
- Less efficient than CO_2 or ammonia system*,**



*Zero Zone study

**Renteknik study

3

The Market Today: Case Studies

3.1 CO_2 Ice Rinks

3.1.1 COLUMBUS (OHIO) BLUE JACKETS TO BE FIRST NHL TEAM TO USE CO_2-BASED ICE RINK SYSTEM

The desire for a future-proof system led Nationwide Arena to select an indirect CO_2 system from CIMCO.

The Columbus Blue Jackets, which joined the National Hockey League (NHL) in 2000, will become the first NHL team to skate on ice produced by a transcritical CO_2 (R744)-based ice rink refrigeration system.

The system, to be supplied by Canadian manufacturer and contractor CIMCO Refrigeration, will be installed next year at Nationwide Arena (the purchaser of the system) in Columbus, Ohio, in time for the Blue Jacket's 2023–2024 NHL season. The indirect system will use CO_2 as the primary refrigerant and glycol as the secondary coolant under two rinks, the main NHL rink and a practice rink.

"CO_2 has had a longstanding reputation in Europe for decades and we are excited to be the first NHL team to implement a CO_2 plant partnering with CIMCO," said Derek Smith, General Manager for Nationwide Arena.

The system consists of two 200TR (703kW) industrial-grade CO_2 packages, each consisting of eight compressors. It also features a seven-pump package for pumping glycol under the two rinks and for heating. The system supplies 5°F (-15°C) glycol for the ice rinks per NHL requirements and "can go lower if needed," said Brad Wilkins, U.S. Recreation Project Team Lead at CIMCO Refrigeration. It includes redundant components in the event of a failure.

Fifteen of the NHL's 32 rinks use another natural refrigerant – ammonia/NH_3 (R717) – in their ice rink systems. Among the rest, 15 (including Nationwide Arena currently) employ R22 or other traditional f-gases, while two use the HFO blend R513A.

Nationwide Arena

"'We are excited to be the first NHL team to implement a CO_2 plant."

– Derek Smith, Nationwide Arena

Only one professional hockey team currently plays on ice produced by a CO_2-based ice rink system – the Cleveland Monsters, the Blue Jackets' top minor league affiliate and a member of the American Hockey League (AHL). The indirect CO_2 system, provided by Zero Zone, was installed a year ago at the Rocket Mortgage FieldHouse, the Monsters' home arena.

This fall, another minor league team, the Reading (Pennsylvania) Royals of the East Coast Hockey League (ECHL), will begin skating on ice made by an indirect CO_2-based ice system, supplied by CIMCO, at the Santander Arena. The Royals are an affiliate of the Philadelphia Flyers NHL team, which uses an R22 system.

CO_2 gas cooler at Santander Arena; Nationwide Arena will install the same model in 2023.

Refrigerant considerations

Nationwide sought to replace its original, 22-year-old CIMCO-supplied system because of the R22 phaseout and the rising cost of the refrigerant, said Wilkins. "They experienced a major leak and a big repair and didn't want to go through that again."

The arena considered an ammonia system but decided against it because it would have required costly engine room modifications and ventilation upgrades.

Nationwide initially leaned toward purchasing an R513A system until learning more about CO_2 technology from CIMCO, said Wilkins. "After extensive research, we determined the smartest choice was a CO_2 solution that CIMCO proposed," said Nationwide's Smith.

The NHL has formed a partnership with chemical producer Chemours to promote the company's R513A refrigerant Opteon XP10. However, individual NHL teams and their arenas are able to make independent decisions about the type of refrigerant and system they will use.

"We worked with the [Nationwide] organization for approximately six months investigating all the options from multiple perspectives," explained Wilkins. "Purely from a business perspective, CO_2 checked of all the boxes and was a proven technology that exceeded the NHL performance standards."

The CO_2 system turned out to be 25% less expensive than the R513A system, which required a special design for glycol piping and installation in the engine room, Wilkins said.

But the cost of the system was not the main factor.

R513A consists of 44% R134a, an HFC that is subject to an eventual phase down in the U.S. It also

CO_2 package at Santander Arena; Nationwide Arena will install two similar packages in 2023.

contains 56% R1234yf, an HFO that breaks down in the atmosphere into trifluoroacetic acid (TFA), which returns to Earth in rainfall and accumulates in water sources.

Following the phaseout of R22, Nationwide did not want to be in the same position again with another refrigerant. "Having a future-proof, efficient, sustainable refrigeration installation that will last for the next 30 years is very important to us," said Smith. "With ever-changing regulation in the industry, we were not interested in having to trouble ourselves with having to find another solution in the coming years."

Another important advantage of the CO_2 system is energy savings. The heat reclaim made possible by the system will be used to preheat hot water and to support snowmelt and underfloor heating. An R513A system would have required an additional natural gas boiler to deliver heat for snowmelt and underfloor heating, said Wilkins.

In addition, an analysis of electricity usage found that the CO_2 system "conservatively" is expected to save 20% compared to an R513A system, said Wilkins.

The CO_2 system will use two Guentner adiabatic gas coolers to bolster its energy efficiency during warmer days. Overall, the water used by the gas coolers will be far less than that used by a cooling tower for an R513A system, a projected savings of $20,000 per year, Wilkins said.

Nationwide opted for an indirect CO_2 system – rather than a direct CO_2 system that would use CO_2 under the two ice rink floors – to take advantage of its existing glycol piping and floors. The lifespan of an ice rink floor and piping is 45 to 50 years, meaning that the 22-year-old floors at Nationwide are only middle-aged. "So there was no reason to replace them," said Wilkins.

CIMCO educated Nationwide on the safety advantages of CO_2. In the event of a leak, CO_2 has an eight-hour safety limit of 5,000ppm, while R513A's limit is 600ppm. "So $CO_2$is more than eight times safer [than R513A] for human beings to be in a room for eight hours, said Wilkins.

In any event, CIMCO will be able to remotely monitor the CO_2 system, and the company's trained local technicians will be available to handle any issues, said Wilkins.

Having installed more than 80 CO_2 ice rink systems since 2014, CIMCO is "very comfortable with CO_2," said Wilkins. "This is not a risk, technology-wise."

Long lead times on equipment has resulted in the installation of the CO_2 system to be scheduled for next year. The exact time will depend on whether the Blue Jackets qualify for the NHL playoffs. Even if the team wins the Stanley Cup championship in June, that will leave enough time to install and commission the system before the beginning of the next season.

ATMO Conferences

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November 2022
Brussels

ATMO WORLD SUMMIT
March 2023
Online

ATMO AMERICA SUMMIT
June 2023
Washington

ATMO AUSTRALIA
July 2023
Sydney

ATMO LATAM
September 2023
Mexico City

ATMO EUROPE SUMMIT
October 2023
Brussels

More info on www.ATMO.org

National Speed Skating Oval (the Ice Ribbon), Beijing 2022 Olympics

3.1.2 BEIJING OLYMPICS PUT GLOBAL SPOTLIGHT ON CO_2 REFRIGERATION AT ICE RINKS

The CO_2 ice rink at the Ice Ribbon was the site of several record-setting performances in speed skating.

As the Beijing 2022 Olympics got underway on February 4, the world was made aware of the first-time adoption at the Games of environmentally friendly CO_2 (R744) refrigeration system at four ice-rink venues.

The International Olympic Committee (IOC) posted an announcement on January 25 on its website, with the headline, "The New Ice Age: Beijing 2022 Winter Olympics debut[s] climate-friendly CO_2 cooling system."

"The Olympic Games are first and foremost a sporting event, but with their global visibility, they also provide an important platform to showcase sustainable solutions," said Marie Sallois, IOC Director for Sustainability, in a statement.

According to the IOC, the use of natural CO_2 refrigerants at the Winter Olympic Games helped reduce carbon emissions by an equivalent of 3,900 cars per year, cutting them to nearly zero; a similar carbon reduction could be achieved by planting about 1.2 million trees.

The CO_2 technology also has a cooling efficiency that is 1.2 times higher than that of HFC refrigerants, and can maintain temperature consistency across ice surfaces, making the ice easier to skate on, added the IOC. This led to several new record performances in speed skating.

Meanwhile, an article by the Associated Press (AP) pointed out that the Beijing Olympics will be "putting a major environmental problem on the world stage — the potent greenhouse gases often lurking in refrigerators, air conditioners and other cooling systems."

“Everyone was talking about the Ice Ribbon and the quality and the speed of the ice."

-- Guy Evon Cloutier, CTC Group

The CO_2 being used in ice skating, figure skating and other competitions at the Olympics has “far less of an impact on global warming than the artificial refrigerants,” the AP article noted. It added that organizers of the Games say the CO_2 cooling “could bring attention to the use of artificial refrigerants globally, which is expected to become a growing problem as developing countries get richer and use more and more cooling appliances.”

The four Beijing 2022 ice rinks that used CO_2 systems are the National Speed Skating Oval (NSSO, aka the “Ice Ribbon”), the Capital Indoor Stadium (for figure skating), the Capital Short Track Speed Skating Training Hall, and the Wukesong Ice Hockey Training Hall.

The Olympics also employed another natural refrigerant – ammonia/NH_3 (R717) – at the National Sliding Center, an indoor/outdoor facility that hosted the bobsleigh, skeleton and luge events.

However, the organizers chose R448A, an HFO/HFC blend with a 100-year GWP of 1,400 (and a 20-year GWP of 3,100) to be the refrigerant at three rink facilities: the National Indoor Stadium, the Wukesong Sports Center and the National Aquatics Center (the “Ice Cube”).

On the whole, the Beijing Olympics committed to staging “carbon-neutral Games,” said the IOC, and the debut of the new refrigeration technology was among the ways in which it reduced the Games’ carbon footprint.

For example, the Beijing Olympics powered all its venues with renewable energy – another “first” at the Olympic Games – and used fuel-efficient and clean-energy vehicles for all passenger cars, and 85% of all vehicles.

In 2021, the IOC joined the UN-backed “Race to Zero” campaign, which is aimed at rallying climate leadership from non-government entities to work towards a carbon-free world.

Multi-purpose ice rink

The NSSO was the only newly built venue in Beijing’s Olympic Park, with a surface of 12,000m^2 (129,167ft^2). It met the competition requirements of five ice sports: speed skating, short track skating, figure skating, curling and ice hockey. Cutting-edge technologies enabled the entire venue to be used for different purposes simultaneously.

The NSSO’s direct expansion (DX) transcritical CO_2 centralized system generated 4MW (1,137TR) of cooling capacity at -18°C (0.4°F) SST and 38°C (100°F) SCT, as well as 3MW of heat. The system used six Carrier PowerCO_2OL compressor racks, each with six compressors and one adiabatic gas cooler; and it included four CO_2 recirculation vessel packages, each with two CO_2 pumps, and vessels connected to common suction and common liquid drains. The floor network employed stainless steel (20mm/0.75in) pipe and stainless steel headers sized to the flow rate.

The NSSO’s DX CO_2 system delivered liquid CO_2 under the ice, producing “hard ice for speed skating and smooth ice for dancing,” said Carrier. The temperature of the ice was −9°C (5.8°F), reported Guy Evon Cloutier, CEO of the CTC Group, an ice-rink consultancy based in China; CTC is part of a consortium with CIMCO Refrigeration that provided consulting services for the NSSO project.

The system was designed by Swedish OEM Green & Cool, and manufactured by Profroid in France; both companies are wholly owned subsidiaries of U.S.-based Carrier. Italian manufacturer Dorin supplied its CD600 and CD400 CO_2 compressors for the project.

In China, the Qingdao Haier Carrier Refrigeration Equipment Company, a joint venture established in 2001 by Qingdao, China-based Haier Group and Carrier, commissioned the transcritical CO_2 system at the NSSO.

The heat reclaimed by the system was utilized for dehumidification, ice surface maintenance, ice melting, floor heating, tap-water and complete-building heating at the NSSO, saving up to 2 million kWh of electricity each year compared to traditional HFC systems.

The NSSO employed a “very special multi-purpose concept” with 10 floor zones that could be frozen individually, or as a whole, becoming a huge ice surface of about 12,000m^2 [129,167ft^2],” said Cloutier.

The 10 refrigerated floor zones included two track zones and two arenas with dedicated pumping systems; the other six zones connected to two pumping systems but with individual zone valves and temperature control.

The Capital Indoor Stadium used a transcritical CO_2 system from Beijer Ref China, based in Wuxi, China. The system consisted of two transcritical CO_2 racks that provide 1.1MW (312.8TR) of cooling capacity with a coefficient of performance (COP) of 2.8. It also included three-stage heat reclaim, which drives the cooling and heating COP to 6.6. German compressor manufacturer BOCK reported that it supplied CO_2 compressors for the Capital Indoor Stadium and other venues at the Beijing Olympics.

Records Set at the Ice Ribbon

The NSSO was the site of a new world record in speed skating and 10 new Olympic speed-skating records.

The world record was set by Nils van der Poel of Sweden in the men's speed-skating 10,000m race; he also set an Olympic record in the 5,000m race. Irene Schouten of the Netherlands set two speed-skating Olympic records – in the women's 3,000m and 5,000m. Her compatriot Kjeld Nuis set an Olympic mark in the speed skating men's 1,500m race.

There may well be a connection between the ice made by the direct transcritical CO_2 system and the multitude of new speed-skating records.

"It's a much different system than in the past. It reacts very differently, and we're finding a lot of great things with the CO_2," said Mark Messer, speed skating ice maker for this and four previous Winter Olympic Games, as well as Plant Manager, Ice and Facility Specialist for the University of Calgary, Canada, in an interview with Reuters. "It's great for the environment for a start, so that's great, but it's very responsive."

"Everyone was talking about the Ice Ribbon and the quality and the speed of the ice," said Cloutier. "The ice is very uniform and steady; it doesn't move – that's the beauty of DX," said Cloutier.

Notably, the new records were set at a much lower elevation than that experienced at the Winter Olympics held in Calgary, and Salt Lake City, Utah (U.S.), where the thinner air provides less resistance for skaters. In fact, Schouten and Nuis broke Olympic records that had been set in Salt Lake City two decades ago.

Because of the COVID-19 pandemic, Messer had less time than at previous Olympics to get the ice at the Ice Ribbon ready for the Games. He was still fine-tuning it as the skaters arrived, and some found it initially too soft, though it improved as the Games got underway. And it turned out to be solid enough to support the slew of record-setting races.

New CO_2 showcases needed

While the success of the Ice Ribbon is a "good story," it would not be practical to try to replicate its technology and design elsewhere, Cloutier noted. "It's important to have new showcases to show the advantages of CO_2 and that it can be cost-effective." Cloutier expects enthusiasm for CO_2 ice-making from the Olympics to carry over to the construction of new ice arenas. He will be working to make that happen with two Chinese companies, including the Beijing Urban Construction Company, a government-run entity that built many sites at the Olympic Games. "If the price is right, the government will support it big-time," he said. This would be helped by the development a new national CO_2 design and safety standard, which is underway.

There are about 200 indoor ice rinks in China, virtually all using f-gas refrigerants. However, the Chinese government is using the Olympics as a platform for expanding winter sports in China, what it calls the "winter dream." Chinese President Xi Jinping is said to be committed to getting some 300 million people involved in winter sports. Over the next decade, that could result in at least 2,000 new ice rinks, and maybe as many as 5,000, said Cloutier.

GREEN AND GOLD IN BEIJING

The Olympic and Paralympic Winter Games that took place in China in February 2022 were like no Olympics that have come before. President Xi Jinping announced his country's intention to make the event as environmentally sustainable as possible, declaring that the Games will be "green, inclusive, open, and clean," in line with the United Nations' Sustainable Development Goals.

For the first time in the history of the Olympics, all the venues – located in the Chinese capital, Beijing, and the neighboring province of Hebei – were wholly powered by green energy, using the rich wind and solar resources of co-host city Zhangjiakou. And rather than build new venues in Beijing, the organizers adapted existing buildings, such as the National Aquatics Center, where the swimming pool was transformed into a curling a.

The one exception was the capital's new National Speed Skating Oval. Known as "The Ice Ribbon," this imposing construction hosted 12,000 spectators during the Games, when 14 gold medals were awarded. The exterior façade of the building, which was designed by architecture firm Populous, is a striking oval cocoon of 22 glass ribbons that symbolize the traces the skaters leave on the ice. At night, the ribbons lit up in changing colors, and during the day, in keeping with the Games' green credentials, they generated electricity, thanks to the photovoltaic qualities of the glass.

Inside, the ice covers 129,167 square feet, making this the largest indoor ice surface in all of Asia. And the technological innovation continues: in another green first for the Olympics, Beijing introduced carbon dioxide transcritical direct cooling for the ice-making process. Juan Antonio Samaranch, Chair of the International Olympic Committee Coordination Commission for the Games, described this as "a landmark decision."

"The speed skating venues during the past Winter Olympics all used Freon refrigerants, but the new refrigerants, made of natural carbon dioxide, have no impact on the environment," said Gui Lin, an official with the Planning and Construction Department of the Games' organizing committee.

The stadium's modular refrigeration system maintained a uniform temperature across the entire ice surface to within 0.9 degrees Fahrenheit; it was constructed by Pan-China Sports. The system was designed by Hua Shang International Engineering, using the expertise of Swedish ice rink specialists EKA and the cutting-edge technology of Haier Carrier and Güntner, who provided six large V-shape VARIO adiabatic Gas Coolers.

"This was the biggest CO_2 project ever in China, so it was a real landmark," says Güntner sales manager Jason Dai. "It was very complex, and we had to make sure the coolers worked perfectly for the whole refrigeration system."

The technology was also extremely energy-efficient compared to what had come before. "The energy consumption of this ice-making system is twenty percent less compared to one based on Freon," said Song Jiafeng, the Ice Ribbon's Executive Deputy General Manager. In addition, the waste heat generated by refrigeration was used for water in the athletes' quarters and ice surface maintenance.

With the games over, the National Speed Skating Oval will be used not only to host ice sports but also as a public ice rink, becoming a hub for the community and supporting China's ongoing involvement in winter sports.

For more information

Güntner

For more information, contact Lady Acuna at 874-781-0900 or visit GUNTNER.com/US.

Anchorage, Alaska

3.1.3 SKATING ON CO_2-MADE ICE IN ALASKA

Anchorage, Alaska, has used CO_2 transcritical cooling systems at its four municipal ice rinks since 2017, as a replacement for R22 equipment.

In Alaska, where ice skating is a favorite pastime, the municipality of Anchorage operates four public ice rinks. All four use a natural refrigerant (CO_2) in a transcritical system to keep the ice frozen – the first in the U.S. to do so.

Anchorage, through its Parks and Recreation Department, finished installation of the first transcritical system at the Harry J. McDonald Recreational Center in December 2014, and completed the second and third at Sullivan Arena and the Ben Boeke Ice Rink in 2016. The fourth CO_2 system was implemented at the Dempsey-Anderson Arena in 2017.

The CO_2 systems were provided by OEM Hillphoenix, based in Conyers, Ga., Hillphoenix submitted an application to the U.S. Environmental Protection Agency asking the agency to list CO_2 as an acceptable refrigerant for ice rinks under its SNAP (Significant New Alternative Policy) program, which the agency later did in May 2016.

John Rodda, former director of the Parks and Recreation Department, launched a thorough assessment of the Department's options in 2013 before deciding to go with a transcritical CO_2 system to replace the R22 cooling systems that had been operating for decades at all of its facilities.

The phase out of R22 as a refrigerant under the Montreal Protocol, along with the aging of the facilities, prompted Rodda to replace all of the existing R22 systems.

"We had an opportunity through state grant funding to receive enough money to do these four facilities," Rodda said. "Sooner or later we were going to be dealing with it."

All of the facilities were built in the 1970s and 1980s, and were using R22 systems to freeze and maintain the temperature of their ice sheets.

"Every building is a minimum of 30-plus years old, and over the course of time, gradually we had a few more problems," Rodda explained. "We had a couple of leaks, and you just have to do something at some stage."

In addition, repair was becoming more difficult for the R22 systems as parts became harder to come by, Rodda said.

Rodda said Anchorage considered a variety of options, including ammonia-based cooling systems, before settling on the Advansor Transcritical Direct CO_2 System from Hillphoenix.

He said he decided against an ammonia system because there would be some additional costs involved for added safety and isolation requirements.

High efficiency

The system chosen by Anchorage delivers high efficiency, said Tim Henderson, Industrial Program Manager, Hillphoenix.

"If they didn't use CO_2 as a replacement for R22, an alternative would be a chiller that uses an HFC, ammonia or CO_2 as a primary refrigerant to chill glycol or brine, which would be pumped under the ice," he said. "But this is inefficient compared to the all-CO_2 transcritical system because the pumping power is up to 90% greater, and there is an extra heat exchange process between the primary refrigerant and the secondary fluid."

The ability to capture as much of the excess heat as possible generated by the cooling system factored into the decision to go with direct CO_2, Rodda explained. The heat has been deployed for other purposes in the facility, thus lowering overall energy consumption.

"We took into account everything we could possibly imagine, and ultimately it came down to efficiencies, and how we could utilize waste heat for additional savings in a system that is able to produce what we need in the facility, and that's ice."

The excess heat is used for a variety of purposes in the facilities, Rodda explained, including for locker rooms, floor heating, and hot water.

Rodda said energy use in the CO_2 system exhibited a fairly consistent pattern in which it did not increase much, as opposed to what it would have been with the R22 system. Anchorage is located in a northern climate favorable to the efficient operation of trans-critical CO_2 technology. Hillphoenix calculates a "theoretical [energy efficiency] advantage" for the CO_2 systems, but that can't be confirmed as data is not available for the previous R22 systems, said Henderson.

Larger charge

The CO_2 system used at the Ben Boeke Arena is similar to the ones at first two other installations, although the Ben Boeke installation includes a larger CO_2 charge because the system is used to cool two ice sheets rather than one (which is also the case for the Dempsey-Anderson Arena).

The systems at the first two installations required CO_2 charges of 4,500lbs (2,041kg) at the McDonald Center and 5,000lbs (2,268kg) at the Sullivan Arena, which is a slightly larger facility. The system at the Ben Boeke Arena was expected to have a charge of about 9,000–10,000lbs (4,082-4,536kg). Although each of the two ice sheets is slightly smaller than the individual sheets at the first two facilities, the overall surface area of the ice is larger at Ben Boeke.

The system gives the Ben Boeke arena managers the ability to set the temperatures independently for each of the two ice sheets — hockey calls for harder ice than figure skating, for example — or to shut one of the ice sheets down during the summer for other activities, such as basketball.

Another consideration in using CO_2 systems is that the higher pressure can create perceived challenges for technicians more familiar with low-pressure systems, but Rodda said that this has not been an issue. He said Hillphoenix sent a team of people to train the technicians in Anchorage on how to work with the high-pressure systems, which are also much more computerized than the previous R22 systems, and can also be monitored and operated remotely.

The closed-loop system works by pumping liquid CO_2 under the ice first to freeze it, then to remove residual heat. When the liquid CO_2 along with some vapor comes back, it goes into a separator vessel, where the gas is sent to the compressor and condenser to be liquefied before being pumped back under the ice again. The vapor also goes through an oil separation system to remove any oil.

Some of the heated vapor, as well as the heat removed from the ice, goes through a heat reclamation system to be used elsewhere in the arena, or rejected to the atmosphere.

Rodda said the system has been well-received by customers who have skated on it. "Does it achieve what it needs to achieve for the best skating experience for the end user? Absolutely," he said. "Whatever you need to do in terms of a set point, it does whatever you want, and the quality of the ice is excellent."

Henderson of Hillphoenix said the Anchorage Parks and Recreation Department has been a standout in the industry in its effort to switch to alternative refrigerants.

"Even as slow to change [to new refrigeration technology] as the industrial refrigeration industry is, the ice rinks industry is even slower," he said. "But they [the Alaska Parks and Rec Department] are committed to the CO_2 technology. They love the technology."

The CO_2 systems have needed routine maintenance. Hillphoenix will be making a re-commissioning trip and training a new service company that will be taking over service and maintenance.

SYSTEM SPECS:

The Advansor CO_2 System from Hillphoenix used in ice rinks includes the following:

- Variable frequency drives that control both the compressors and the CO_2 pumps for capacity control and energy savings.
- Semi-hermetic reciprocating compressors, with vibration dampers and capacity control for quiet operation and temperature control.
- A closed CO_2 system with high pressure, using up to 90% less pump power compared with traditional systems.
- A UL-listed and custom manufactured control panel.
- A two-stage, factory-piped self-contained heat reclamation system with a glycol pump that can use waste or reclaimed heat for other parts of the facility.
- Oil separators and a large oil reservoir.
- A large-capacity CO_2 liquid-holding receiver.
- An energy-efficient gas cooling system, using variable speed fans.
- A copper-tube, aluminum fin surface for heat transfer.
- Direct air cooling.

3.1.4 CO_2 REFRIGERATION HELPS CANADIAN ICE RINK SAVE CA$3,500/MONTH

Heat recovery produces warm glycol that is used for producing hot water, heating the grandstands and melting snow in the snow pit, cutting gas usage by more than 40%.

Centre Sportif Sainte-Anne-des-Plaines, a nonprofit community ice rink in Quebec, Canada, is saving an average of CA$3,500 per month in energy expenses during normal operation with an Eco Chill transcritical CO_2 refrigeration system from Canadian contractor CIMCO Refrigeration.

The system went live in September 2020 as part of a renovation of the 27,500ft^2 (2,555m^2) ice rink, in the town Sainte-Anne-des-Plaines, a community of 15,000 people near Montreal. The rink opened in 1994.

"Our goal [was] to save CA$50,000 a year," said Roberto Marandola, Director at Centre Sportif Sainte-Anne-des-Plaines. "A lot of people told me I was dreaming."

However, the facility is close to that goal, thanks to the efficiency of the CO_2 refrigeration system, the heat recovery made possible by that system, and other energy-efficiency measures such as transitioning to LED lighting in 2019.

Heat recovery produces warm glycol that is used for producing hot water, heating the grandstands and melting snow in the snow pit. The facility still utilizes gas heat for hot water, but the amount of gas used at the facility has been cut by more than 40%, said Marandola. "The heat recovery is amazing," he said.

Overall, Marandola has had "zero issues" with the CO_2 system. "I have nothing but praise for it."

The ice rink, with room for 300 spectators, hosts a variety of activities, including minor-league hockey games and public skating. It's also used by the physical education program of a nearby high school.

Secondary brine system

The CO_2 refrigeration system has a capacity of 72TR (253.2kW) and a CO_2 charge of 760lbs (345kg). It uses brine as a secondary fluid under the ice. "Brine works better with CO_2 than with R22," said Marandola. To enhance the freezing process further, the facility cleaned out the pipes under the rink and insulated its largest water tank.

The ice is maintained at 21°F (-6°C) during use and 23°F (-5°C) at night. The supply temperature of the brine is 15.4°F (-9.2°C) and the return temperature 17.6°F (-8°C).

Centre Sportif Sainte-Anne-des-Plaines previously ran an R22 refrigeration system. When the arena's management decided to retrofit the system, environmental concerns were considered, but the "main goal was to save money with a system that would reduce energy costs," according to CIMCO Refrigeration.

The system's flexible control system was also an attraction. "The automation group technology allows the facility to adjust temperatures remotely, something that has come in especially handy during the pandemic when working from home has been necessary," he said. The facility has also been routinely closed because of lockdowns and curfews, which has required temperature monitoring multiple times during the day.

The refurbishment was financed by a grant of CA$712,000 from Quebec and a subsidy of CA$40,000 from the utility Hydro-Quebec. With the provincial grant, the arena posted a sign saying, "Your government making use of public taxes." The cost of the CO_2 system, before applying the grant and subsidy, was CA$1,350,000.

Why CO_2?

Municipal officials in Sainte-Anne-des-Plaines ruled out replacing R22 with another fluorinated refrigerant. “They thought, ‘Eventually those will be eliminated and we will be back to square one,’” noted Marandola. That left CO_2 and ammonia as options.

Given the arena's location in a residential neighborhood, a feasibility report recommended CO_2 as opposed to ammonia, calling CO_2 “the “optimal and safest choice” for its minimal toxicity and zero flammability, though CO_2 detectors are still required. Marandola noted that the fatal ammonia accident at an old, poorly maintained system in Fernie, British Columbia, also influenced the decision to choose CO_2, though he pointed out that the risks of modern ammonia systems are minuscule.

Some of Marandola’s peers challenged him on his choice of CO_2 for the new refrigeration system, but he held firm, recognizing that the opinions were based on anecdotal evidence, and came from experiences that occurred close to a decade ago, when CO_2 technology was in its infancy.

“I went to visit all kinds of CO_2 systems beforehand to see the technology in action, but this system is totally different,” Marandola explained. “In terms of ice quality and maintenance, the ice freezes incredibly quickly, something the Zamboni driver noticed immediately.”

“By the time they do their full turn, it’s frozen—there’s no waiting,” said Marandola. “The ice is also harder, and nicer to skate on.”

Marandola also pointed out that, while transcritical CO_2 refrigeration is relatively new for ice rinks, many supermarkets in Quebec use the technology. “Their compressor rooms are the same as ours,” he said.

CO_2 rack at Centre Sportif Sainte-Anne-Des Plaines

Rink at St. Michael-Albertville Ice Arena

3.1.5 FIRST U.S. CO_2 ICE RINK CHILLER DOES DOUBLE DUTY

St. Michael-Albertville Ice Arena replaced an R22 system with a CO_2 chiller to support an old ice sheet and a new one.

In 2018, the St. Michael-Albertville (STMA) Ice Arena, in Albertville, Minnesota, became the first ice arena in the U.S. arena to install a transcritical CO_2 chiller system.

The 170-TR "ColdLoop" CO_2 system, supplied by U.S. OEM Zero Zone, replaced an R22 chiller that served an existing rink, cooling the same glycol loop that runs under the rink. The CO_2 chiller also delivers cooled glycol to a second, newly constructed rink.

As an ice facility using transcritical CO_2 refrigeration, the STMA Ice Arena was preceded in the U.S. only by four municipal rinks in Anchorage, Alaska, that installed direct CO_2 systems in 2016 and 2017.

The towns of St. Michael and Albertville, Minnesota share the arena and a school district, which owns the new ice sheet and co-owns the original sheet with the towns.

Ice skating is so popular in St. Michael and Albertville that one sheet of ice was no longer sufficient to meet the communities' demands for skate time, and a second sheet was needed, according to a case study on the arena published by Zero Zone on its website.

The STMA School District decided to use a CO_2 glycol chiller for both the original rink and the new one after considering an ammonia chiller. The decision was also made to install a chiller system

"An Olympic skater had a program here and that Olympic skater found that it was the best that they had skated on."

— Terry Zerwas, St. Michael-Albertville Arena

with glycol pumped under the rink, rather than direct system pumping CO_2 under the rink, in order to maintain a consistent temperature across both rinks, said Justin Zembo, a service technician for Minnesota-based St. Cloud Refrigeration (SCR). SCR installed and services the CO_2 chiller system. "For simplicity's sake, we decided to go with glycol for the new sheet."

The idea for a CO_2 system, never before implemented at an ice arena in the continental U.S., was broached to the STMA School District by SCR. "We were looking for an opportunity to do a CO_2 system in an ice rink, and mentioned it," said Zembo. "They were also interested in it." After the discussing the technology with Scott Ward, an engineer with B32 Engineering Group, the STMA School District opted for the CO_2 system.

The STMA School District appreciates that the system uses CO_2, a natural refrigerant. "They knew first-hand the struggles with a synthetic refrigerant and the cost fluctuations, because they used R22," said Zembo. "They were looking for an alternative and it appealed to them that they wouldn't have to worry about the future of CO_2. They liked that it's future-proof."

The STMA School District also appreciated the "prestige" of being the first CO_2 chiller user in the U.S., he said.

In the Zero Zone case study, Terry Zerwas, the STMA Director of Buildings and Grounds, was described as an "early advocate for the CO_2 system because he had heard that Canada was successfully using CO_2 for ice arenas. "Let's be a trendsetter and put it in," he said, adding that the transition from R22 to CO_2 was "flawless."

"An Olympic skater had a program here," noted Zerwas in the case study, "and that Olympic skater found that it was the best that they had skated on."

STMA Arena Manager Grant Fitch said in the case study that he believes CO_2 could be "the future" for ice rinks.

Heat reclaim is used for melting snow collected from resurfacing the ice and for permafrost prevention under the ice rink floor.

The case study cited energy cost savings with the CO_2 systems. During the hottest months in previous years, the arena would experience energy costs of around $8,000 for a single sheet of ice. With the CO_2 system, costs were only $11,500 for both sheets of ice during an unusually hot summer, a 28% reduction. In addition, a local energy cooperative provided a study of the ice arena, concluding that the arena, including the CO_2 system, was highly energy efficient.

Well-functioning system

The STMA Arena was SCR's second or third CO_2 project; the others were for supermarkets. Since then, SCR has installed many more CO_2 systems in stores. But SCR went about the ice rink installation "confident that we would get the system operating properly," said Zembo.

Overall, Zembo's assessment is that the CO_2 system "functions well." Not that there aren't challenges. In particular, the vicinity around the arena is prone to "power quality issues" leading to brown outs and voltage spikes that "knocked the VFD off line," he said.

There are also power outages, which requires SCR to "shut down the system safely so that it can be restarted easily," said Zembo. In addition, SCR prefers to manually restart the system rather than allowing it to restart on its own.

There have been times when the evaporator relief valve expels some CO_2 gas following a power outage. "It's the first to let CO_2 out because it has the lowest pressure rating (around 400-550psig)," said Zembo. But that doesn't hamper the operation of the system as SCR gets a low-refrigerant notification and replaces the lost gas.

Of course, a continuing challenge is the availability of components, which can take up to six months to receive.

High pressures in a CO_2 system, which is typically rated up to 1,740psig, should not concern ice rink owners and managers, said SCR Owner Mark Fitch in the case study. "Every component is built to deal with this pressure," he said, comparing the system to other high-pressure applications in homes and apartments.

The targeted saturation suction temperature of the CO_2 system is 5°F (-15°C), though it can be "floated up or down" depending on the temperature of the ice, noted Zembo. The glycol temperature under the ice ranges from 15 to 18°F (-9.4 to .7.8°C). The arena management can adjust the temperature from outside the mechanical room. In this regard, the CO_2 chiller system works the same as any chiller system, he added.

Other components include a Guentner adiabatic gas cooler, a plate-and-shell flooded CO_2/glycol heat exchanger, a brazed-plate desuperheating heat exchanger that warms glycol with discharge gas for heat reclaim, a Micro Thermo control system, and a CO_2 charge of 1,500lbs (680kg). The mechanical room contains an infrared multi-zone leak detection system linked to ventilation and exhaust fans.

Zero Zone, the provider of the CO_2 system, is located in Ramsey, Minnesota, near the arena, and provided on-site and remote support during the first year.

2022 Natural Refrigerants ATMO Approved

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ATMOsphere Natural Refrigerants Label

ATMOsphere has launched a global industry label to meet growing market demand for a quality label that qualifies and celebrates the best natural refrigerant companies and products.

Aimed at natural refrigerant manufacturers (both system and component), our custom process considers company vision, customer satisfaction, and measurable impact.

atmosphere.cool/natural-refrigerants-label/

3.1.6 FINNISH ICE RINK SAVES 30% IN ENERGY CONSUMPTION WITH CO_2 RACK

The system in Pirkkala also includes a two-stage heat recovery system and is billed as 'one of the most sustainable and cost-efficient' ice rinks in the world.

An ice rink in Pirkkala, southwestern Finland, has reduced its annual energy consumption from 500MWh to 350MWh, a saving of 30%, by replacing an old R404 system with a new CO_2 (R744) rack with two-stage heat recovery.

This makes it "one of the most sustainable and cost-efficient [ice rinks] in Finland and the world – while also increasing comfort in the previously cold arena room which now is heated," according to a LinkedIn post by Jörgen Rogstam, Managing Director of EKA – Energi & Kylanalys, a Swedish consultancy firm specializing in ice rinks. EKA designed the new Pirkkala ice rink system.

The LinkedIn post was in response to a person who favored ammonia/NH_3 (R717) and claimed that "CO_2 doesn't work in ice rinks."

"There is absolutely nothing wrong with ammonia," Rogstam stressed, "but, correctly designed, CO_2 performs even better in an ice rink."

The Pirkkala CO_2 system

The CO_2 rack installed at the Pirkkala ice rink has a cooling capacity of 250kW (71.1TR). It is connected to the existing rink floor, where the secondary refrigerant is Freezium, a solution of potassium formate. The new system was installed by Finnish company Suomen Tekojää Oy.

The two-stage heat recovery system covers all heating demands in the arena, including the dehumidification system, which was redesigned to secure the moisture handling of the roof structure. The only exception is the sauna, which is mandatory in Finnish ice rinks.

Originally the municipality wanted the arena room to be unheated to save energy. However, with the new CO_2 system, the room could be heated in a sustainable way. "This would improve comfort remarkably and also cause a steady heat load on the ice, which is necessary to maintain a continuous heat recovery process to cover demands," EKA explained.

The Pirkkala CO_2 ice rink operates eight months a year, from August to March. The arena has one ice sheet and an audience capacity of around 600, which is typical for ice rinks in Finland, according to a case study on EKA's website. EKA started redesigning the system in 2018.

Initially after the installation of the new system, the Pirkka municipality struggled to control the new system optimally and achieve the expected savings. EKA helped bring the project back on track and in the 2020–2021 season the energy consumption was reduced from 500MWh to 350MWh. The improved control strategies helped both the Pirkka municipality and the contractor. "Positive feedback was given from the contractor that their learning curve in this modern technology was also being improved," EKA said.

Pirkkala is not the only town to see significant savings with CO_2 refrigeration systems in ice rinks. The city of Aarhus in Denmark has saved 50% in energy by installing a CO_2 rack in its municipal ice rink, as well as a floor with CO_2 pipes underneath rather than a secondary system. That system was designed and manufactured by the Danish company Advansor.

DORIN'S LARGE CO_2 COMPRESSORS TAKES INDOOR SKI VENUES TO THE NEXT LEVEL

Norway's SNØ Arena shows how CO_2 can be safely, cost effectively and efficiently used in winter sport venues' refrigeration systems.

Winter sport venues are very popular in many countries worldwide. Efficient refrigeration systems are at the heart of such sites as they typically feature large energy draws. Another key consideration for the selection of the refri-geration system is related to the comfort and safety of the large amount of people typically gathering at winter sport venues.

CO_2 is non-toxic (in the classical sense) and non-flammable so it can be considered as a very good refrigerant for such industrial refrigeration applications. However, its main limitation was the unavailability of large transcritical compressors needed to cost efficiently cope with the large duties normally involved, as well as possible efficiency penalties for those systems operating all year around, e.g. during warmer seasons.

However, with the usual strong focus on market requests, Dorin has once again shaped the future and recently developed and launched the largest CO_2 transcritical compressors range, with displace-ments up to 60 m3/h and 100HP electric motor size. This made it possible to cost-effec-tively introduce CO_2 transcritical technology into industrially sized systems, such as refrigerated warehouses and ice arenas.

At the same time, leading rack builders have managed to boost the energy efficiency of their systems by implementing new components, such as ejectors, and by integrating comfort heating in their equipment, making the venues totally energy self-sufficient by only using the refrigeration units heat reclaim.

"Excellent Performance" in Norway

The aforementioned improvements (large Dorin CO_2 compressors, ejectors, heat reclaim) made it possible to use CO_2 transcritical technology in various sites, including the famous SNØ Arena, in Norway.
This venue features 35,000m2 (376,737ft2) of total snow area with an elevation of 90m (295ft) and is powered by 3.5MW (995.2TR) of refri-geration capacity delivered only by three CO_2 transcritical refrigeration racks.
The units have already been successfully commissioned and the site is up and running with excellent performance levels. This confirms that CO_2 can be safely, cost effectively and efficiently used in winter sport venues' refrige-ration systems.

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3

The Market Today: Case Studies

3.2 Ammonia Ice Rinks

3.2.1 REFLECTING AMAZON'S 'CLIMATE PLEDGE,' SEATTLE KRAKEN'S ARENA USES AMMONIA SYSTEM FOR ICE RINK

The Climate Pledge Arena is the first arena in the world targeting net-zero-carbon certification by the International Living Future Institute (ILFI).

The Climate Pledge Arena in Seattle, Washington (U.S.), home to the Seattle Kraken National Hockey League (NHL) team, employs an ammonia chiller system as part of a wide-ranging effort to make it the first arena in the world to be certified net-zero-carbon. The ammonia system was supplied by Liverpool, N.Y.-based IceBuilders.

Previously named the KeyArena, the facility underwent a renovation that was completed in October of 2021. Online retail giant Amazon acquired naming rights to the arena, and renamed it Climate Change Arena; the name refers to the "Climate Pledge," launched in 2019 by Amazon and Global Optimism, which calls on signatories to be net-zero-carbon across their businesses by 2040. The arena was funded with significant investment from Amazon and Oak View Group, which will operate the facility.

“Climate Pledge Arena will set a new sustainability standard for sports and event spaces around the world."

– Jason F. McLennan, Founder of the International Living Future Institute

Ownership of the arena is now shared by Seattle Kraken Hockey, Oak View Group and Seattle Center.

According to the NHL, the refurbished ice rink features “the greenest ice in the world using rainwater, refrigerants with zero greenhouse gas emissions and electric Zambonis.” An industry source who declined to be named confirmed that the refrigerant is ammonia; details on the system were not available.

Rainwater harvesting is used to collect rainwater off the roof into a 15,000gal (56,781ltr) cistern; the water is employed for resurfacing the hockey rink ice (“rain to rink”).

Though the arena will use an ammonia-based refrigeration system, the NHL has promoted ice-making systems that use HFO blends, following an agreement it struck with Chemours in 2018, which the league said supports the NHL Greener Rinks Initiative.

“It’s great to see this flagship rink using a truly sustainable refrigerant, but at this point there’s no excuse for the NHL not to be using natural refrigerants in all ice rinks,” said Christina Starr, Climate Policy Analyst for Washington, D.C.-based Environmental Investigation Agency (EIA).

“It’s been very disappointing to see the NHL endorsing [HFO blends] with hundreds of times the climate impact of natural refrigerants, when [15] NHL rinks already use ammonia.”

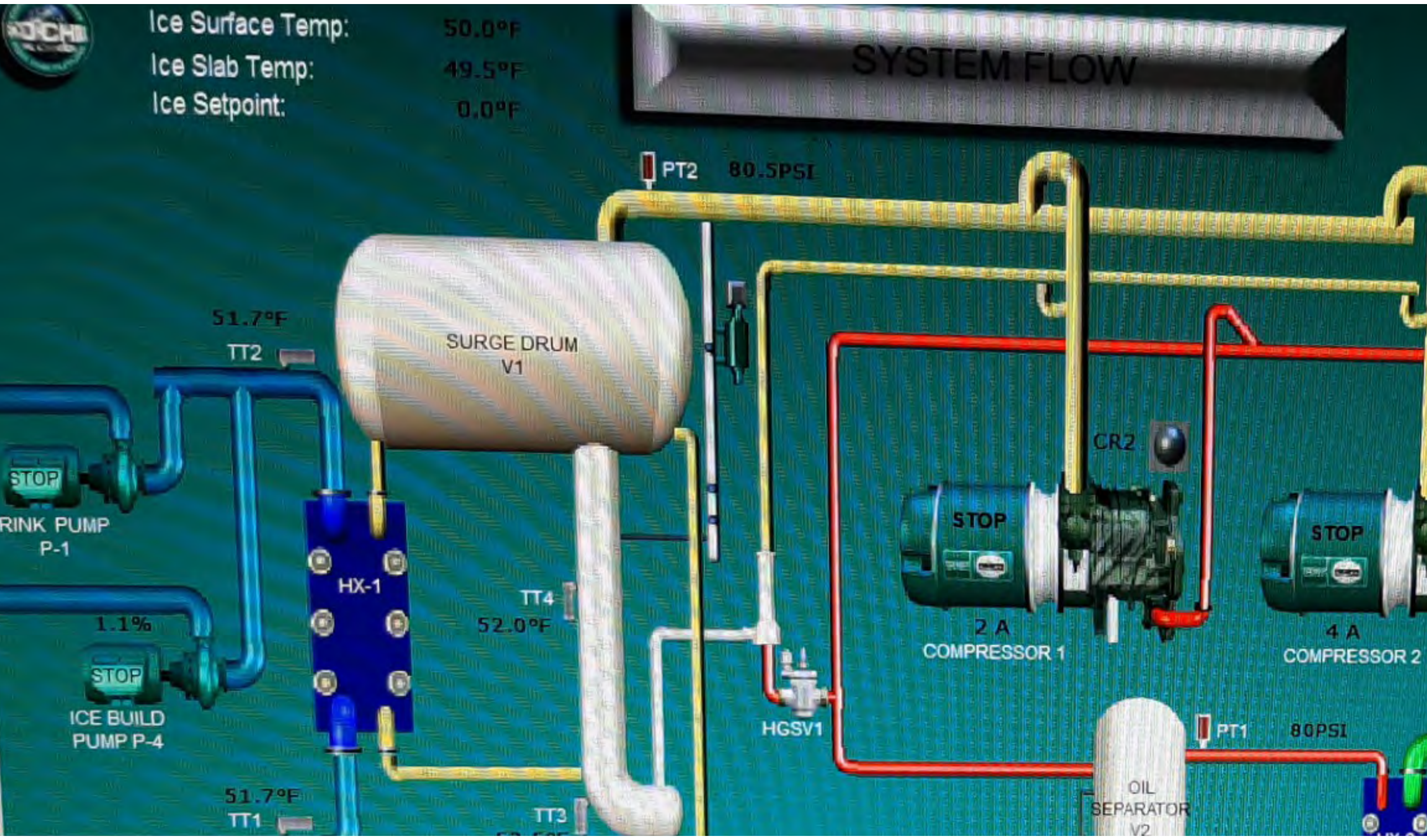
CO_2 refrigeration – to be used by the Columbus Blue Jackets NHL team – offers another sustainable and cost-effective option, Starr noted, adding, “Any ice rink project that adopts an HFC is quite simply not choosing a green option.”

Other environmental features

According to Amazon, the Climate Pledge Arena’s other environmental features include the following:

- It is the first arena in the world targeting net Zero Carbon certification by the International Living Future Institute (ILFI)
- Carbon emissions and sustainability performance of the arena and all events are measured and publicly disclosed
- The arena has all-electric operations and is powered with 100% renewable electricity, both from on-site solar panels and off-site renewable energy. This includes mechanical systems, gas combustion engines, heating, dehumidification, and cooking. Events at the arena are made fully net-zero-carbon through investments in forestry projects with organizations such as The Nature Conservancy that will sequester any remaining carbon emissions from arena operations
- All operations and events at the arena are “zero waste” with durable and compostable containers. A minimum of 95% of all arena waste is diverted from landfills on a weight basis.

“Climate Pledge Arena will set a new sustainability standard for sports and event spaces around the world,” said Jason F. McLennan, Founder of the International Living Future Institute and CEO of McLennan Design, in the Amazon announcement.



Schematic of Dufferin Arena refrigeration system

3.2.2 EMBRACING HEAT RECLAIM, AMMONIA ICE RINK SLASHES NATURAL GAS USAGE

The Dufferin Arena also makes use of an “ice battery” during the winter to reduce its use of the electrical grid.

By employing a natural refrigerant with a zero GWP and superior thermodynamic properties, ammonia-based refrigeration systems are intrinsically good for the environment. But the environmental benefits of such a system don’t have to stop there.

Dufferin Arena, in Stratford, Ontario, Canada, not only uses an ammonia chiller to maintain its ice rink, but also leverages the waste heat from the system (1,200MBH at full-load capacity) to drastically reduce its reliance on natural gas. In addition, the arena makes use of an “ice battery” during the winter to reduce its use of the electrical grid, and employs variable-speed drives (VFDs) for Bitzer compressors and cooling-tower fans. The building also features a “green” roof garden, polymer glass for daylighting, and lighting upgrades; solar panels were scheduled to be installed.

Originally the site of an outdoor rink, the Dufferin Arena was built in 1971 and remodeled with its current refrigeration system – the Eco Chill low-charge (130lbs/59kg) ammonia chiller from Canadian manufacturer/contractor Cimco, with a capacity of 80TR (281kW) – in 2010; the remodel expanded the facility from 20,000ft^2 to 30,000ft^2 (1,858m^2 to 2,787m^2).

"The existing facility when I came in 2009 was horribly inefficient and needed upgrades to bring it to modern standards; it was a real energy pig," said Jim Bryson, former manager of community facilities for the city of Stratford.

The upgraded refrigeration technology, along with other efficiency measures, has cut Dufferin Arena's annual electricity bill by about CA$53,000 (US$38,463) – more than 50% – compared to another comparably sized, single-rink arena in Stratford.

In terms of natural gas, the use of heat from the refrigeration system reduces annual natural gas costs by about CA$6,000 (US$4,355), approximately two-thirds, compared to the other arena.

In its use of heat reclaim, the Dufferin facility is staking out relatively new ground among ice rinks. "Typical arena refrigeration systems do not have heat recovery, and are wasting all of that free heat and dumping it out of the condenser," said Brad Wilkins, Cimco's U.S. Recreation Project Team Lead. The Dufferin Arena's energy upgrades represent one step in Stratford's goal to generate net-zero emissions by 2035. "That's a very aggressive target, and it may be affected by what [we did] with COVID-19," said Bryson. "However, it's achievable, and comes down to retrofitting a lot of buildings."

Heat reclaim plus ice battery

The Dufferin arena uses three Alfa Laval plate-and-frame heat exchangers to execute heat reclaim. (Another is utilized for chilling the glycol via ammonia evaporation.) The first heat exchanger receives hot ammonia gas from the compressors, which sheds the heat to glycol returning from the ice rink. The hot glycol is then used to heat the dressing room and hallway area, to melt snow and ice gathered by the Zamboni in the snow-melting pit, and to warm a concrete path used by the Zamboni.

The hot glycol is also channeled to a second heat exchanger where it pre-heats potable boiler make-up water. Finally, the hot glycol is sent to a third heat exchanger where excess heat is rejected to water, which is directed to a rooftop Evapco water tower.

To reduce the energy consumption of the compressors, the facility maintains a Cimco ice battery – a large insulated container filled with ice – on the roof. During the winter, when temperatures in Ontario drop below -15°F (-26°C), glycol can be chilled in the ice battery rather than through the chiller system, and channeled to the ice rink. "Only if [the rink] doesn't capture the desired temperature will the compressors kick on," said Bryson.

However, since the ice battery system doesn't generate waste heat, a small back-up boiler using natural gas steps in.

The rehabilitation of the Dufferin Arena cost CA$4 million (US$42.9 million), half of it coming through the Canadian federal government's Recreational Infrastructure Canada (RinC) energy-efficiency program. The refrigeration system itself, including heat reclaim, cost about CA$930,000 (US$675,000).

In obtaining the other half from the city government, Bryson presented a year-by-year breakdown in the operational cost savings of the project over 75 years, compared to that of the existing facility. He applied RETScreen clean energy management software to do the calculations. "Where a lot of project managers fail is they just talk about the [initial] capital cost, not what it's going to cost over 75 years," he said. "When you show why this is cheaper, then the politicians start to understand."

Bryson encourages municipal managers and other not to give up on ambitious projects. "You're going to be challenged by people who don't have your vision," he said. "But when you are told no, try and try again."

Compressor room, Pickering Ice Arena

3.2.3 AMMONIA IS A NO-BRAINER FOR ONTARIO ICE RINK

The City of Pickering is confident in the safety of well-maintained ammonia-based ice rink systems.

When the city of Pickering, a suburb of Toronto, Ontario, Canada, decided to replace an old ammonia ice rink system in 2019, there was never any question about which refrigerant the new system would use.

Ammonia.

“Right from the beginning, it was never even a suggestion or even discussed to look at an alternative refrigerant,” said Kevin Hayes, Manager of Facilities Maintenance for Pickering. “Ammonia is just such a normal thing in this area for arena refrigeration. It’s a very efficient gas.”

Hayes oversees two municipal arenas in Pickering, one with three ice pads, one with two. Each facility runs two ammonia-based refrigeration systems. In 2019, the city decided to replace a 25-year-old ammonia/brine system serving the O’Brien rink at the Chestnut Hill Developments Recreation Complex.

The new 573kW (163TR) ammonia/brine system was manufactured and installed by Toronto-based contractor Black & McDonald, with input from TS Engineering, and designed by engineering firm I.B. Storey. It handles one ice pad, producing 23°F (-5°C) ice, with brine entering under the rink at 10 to 13°F (-12 to -11°C) and leaving at 13 to 16°F (-11 to -9°C).

Pickering decided to stay with ammonia despite the fatal ammonia accident that took place two years earlier in Fernie, British Columbia, Canada, killing three technicians. The accident was attributed to neglect of an antiquated refrigeration system. In fact, Pickering's old system was similar to the one in Fernie and "getting to the point where we could have run into" a similar predicament, noted Hayes. However, Pickering avoided that by "having a replacement plan in place."

A catastrophic refrigeration accident, he added, "could happen with any equipment, Freon or ammonia." But ammonia, unlike f-gas refrigerants, is "self-alarming" due its odor.

During his 30-year tenure, Hayes has not observed a dangerous equipment failure in an ammonia rink. "We've had small fitting or valve packings leak but never an emergency situation," he said. In one case a service contractor accidentally split a shell-and-tube condenser pipe during cleaning, causing a leak, and he simply exited the premises.

"Properly maintained with trained staff, ammonia systems are really not an issue," Hayes said, allowing that oil draining might release a little "stinky" ammonia, but "it's controlled."

In Ontario, safety regulations generally call for ammonia systems to be overseen for eight hours per day by a licensed technician. The rule does not apply to f-gas systems, though "they are still specialized systems" that require "competent and qualified staff," Hayes noted.

Better efficiency

The new ammonia/brine system differs in several respects from the original. Notably, while the original used shell-and-tube heat exchanger, the new one employs a plate-and-frame heat exchanger.

The switch enables the new system to limit its charge to around 600lbs (272kg) of ammonia – half the charge of the original system – and to improve the system's efficiency. "Many tubes in the old heat exchanger were getting plugged, and the flow was not as good, so you'd lose efficiency," Hayes said.

Another change was in compressor power. While the old system used three 30HP compressors and one with 50HP (for a total of 140HP), the new system employs two 75HP compressors, to increase total power by 10HP. (All compressors, old and new, are Mayekawa's MYCOM units.)

The superior efficiency of the new compressors means that, while in the past all four compressors had to run to produce the desired ice temperature, now just one will do the trick. "It's rare that we're running both at the same time," said Hayes. As a result, the system requires 25% less hydroelectric power than it did three years ago, he added.

"Ammonia is just such a normal thing in this area for arena refrigeration. It's a very efficient gas."

– Kevin Hayes, Manager of Facilities Maintenance for Pickering, Ontario, Canada

At left: white evaporative condenser water tank; at middle, rear: blue plate-and-frame heat exchanger, Pickering ice arena.

3.2.4 STANDING UP FOR AMMONIA

Ammonia continues to be the go-to refrigerant for design engineer Mike Fairey and his ice rink clients in Ontario.

Mike Fairey, Design Engineer for Canadian ice-rink design firm TS Engineering, has designed as many as 40 ice rink refrigeration systems in Ontario, all of them using ammonia as the refrigerant.

“We haven’t done CO_2 ice rinks yet,” he said.

As for rinks using f-gas, “if clients want that, they have to find someone else.”

Fairey describes f-gases as having a chemical formula “as long as my arm.” Why would anyone want to use that, he wonders, “when you can have something naturally occurring?”

The science speaks for itself. “It’s clear which is better in performance efficiency and effect on the environment; naturals have them beat in every category,” he said. “It boggles my mind that this argument has gotten so twisted and distorted.”

As for the safety of ammonia, “the code is in place with all the safeguards built into the system room,” including gas detectors and ventilation systems, as well as system design parameters, he said. If those safeguards are in place, “you shouldn’t have an issue.”

Systems that leak a lot of f-gas can suffocate a technician, but unlike ammonia, f-gases are odorless and don’t issue a warning, he noted.

Moreover, according to Fairey, the cost of new f-gas blend systems exceeds that of ammonia systems. "The [f-gas] equipment should be cheaper,” he said, attributing the higher price to the marketing partnership chemical producer Chemours has with the National Hockey League (NHL). The “NHL shield provides star power,” he said.

In Ontario, ammonia systems generally need to be monitored for eight hours daily, with variations depending on a system’s horsepower. An exemption exists for ammonia skids that keep the refrigerant confined to the skid, though these only account for 2% of all ammonia systems.

While some operators allow remote maintenance of their ammonia systems, Fairey recommends that technicians are physically present eight hours per day.

Ice rinks systems typically contain less than 1,000 lbs (454kg) of ammonia, not nearly as much as other industrial applications have. As a result, charge size is not as big an issue in ice rinks, though some rinks are reducing their charge to around 300lbs (136kg) for a single ice pad, said Fairey.

Fernie not an issue

The 2017 fatal ammonia accident at a rink in Fernie, British Columbia, has been promoted by the chemical industry as a cautionary tale, but a report by WorkSafeBC on the incident reveals that the system operators “didn’t take care of the system; it was complete mismanagement,” Fairey said, adding, “It doesn’t matter how safe a system is, if you don’t do the basics you are going to have a problem.”

In Ontario, where ammonia is still used in more than 85% of the ice rinks, the Fernie incident has not led operators to switch to f-gas blends like R513A that are being promoted by Chemours and the NHL. “There’s not a lot of support for them in any of the municipalities I work in,” he said. "If City Hall wanted to change [from ammonia], it would get pushback from most of the operators, who want to stick with ammonia.”

“They think, ‘Ammonia is tried-and-true. Why change?’” he added. “And other people say it’s the most environmentally conscious decision you can make.”

CANLAN'S YORK FACILITY ACHIEVES SIGNIFICANT SAVINGS WITH MAYEKAWA MYCOM COMPRESSOR RETROFIT

As a result of the compressor retrofit, the York facility became Canlan's most energy efficient facility, achieving annual savings of 1,500,000 kWh or CAD$300,000 (US$232,000/ €223,000).

Canlan Ice Sports maintains 57 ice surfaces in 18 facilities in Canada and the US. Mycom is a Mayekawa brand and since the Mycom M-series's North American debut in 2008, Canlan has replaced 16 of their legacy compressors, both screw and reciprocating, with Mycom's 6M model.

In 2016, Canlan decided to also replace the compressors at their eastern flagship facility located on the York University campus with Mycom 6M ammonia compressors to reduce energy and operating costs.

About the Project

The York facility is served by a 289.2TR (1,017kW) ammonia refrigeration system. During the 2016 upgrade, three screw compressor units were replaced with three Mycom 6M reciprocating compressors, reducing the total horsepower from 750 to 375 (560 to 280kW) while still managing to improve the quality of ice.

In addition, the 6Ms are operated on low revolutions per minute (RPM) which significantly reduces maintenance and wear. Glycol pumps and chillers were also changed to improve energy efficiency.

A Happy Client

Todd Langer, National Manager – Facility Operation at Canlan Ice Sports Corps, is very happy with the upgraded system. "We are seeing great results. In the month of October [2018], York has been our most energy efficient facility amongst all Canlan buildings," he said.

"With the cost of energy being at its historical highs and the awareness of global warming so prevalent in society, the [Mycom M-series compressor] helps us stay true to our mission and values," said Langer.

For more information

MAYEKAWA MYCOM

For more information, contact customerservice@mayekawa.ca for Canada, or info@mayekawausa.com for the U.S.

U-Turn installation in Canlan Sports arena Burnaby EightRinks

ALFA LAVAL REDUCES CANLAN'S ENERGY CONSUMPTION IN ONGOING AMMONIA SYSTEM UPGRADES

Canlan Ice Sports has achieved an electricity reduction of over 10M kWh by upgrading seven of their facilities and replacing shell-and-tube equipment with Alfa Laval's plate heat exchanger technology

Canlan Ice Sports welcomes 14 million people every year in their 22 facilities in North America, equipped with 60 sheets. Starting in 2013, the company began a program of modernizing and upgrading the chillers and heat exchangers for underfloor heating at the ice sports facilities that they own and operate in North America, starting with Oakville (Ontario, Canada).

Canlan has already upgraded five facilities in Ontario, and two more in British Columbia (Canada) – all of them ammonia refrigeration systems. They have plans to complete upgrades at all their operating sites in Canada and the United States.

These planned upgrades have dramatically lowered the overall refrigerant charge required, contributed to a reduced overall annual electricity consumption by over 10 million kWh and utilizing a refrigerant with zero Global Warming Potential (GWP).

ABOUT THE UPGRADES

The seven sites already upgraded featured a mix of new built installations and retrofits, ranging in refrigeration capacities of between 80 to 360 TR (281 to 1,266kW) per site.

How was the equipment these sites upgraded?

1. Changing the rink's chiller equipment to install Alfa Laval's plate heat exchanger technology

By changing the shell and tube chiller to a more efficient plate and frame heat exchanger, the process is much more responsive and with a higher suction temperature from the heat exchanger, reducing the load on the compressors. Once the compressor runs at the higher suction temperature the rink accomplishes energy savings of approximately 3%.

2. Changing the surge drum to a more efficient and compact separator, Alfa Laval's U-Turn

Implementing an Alfa Laval U-turn ammonia separator optimizes the evaporation process, allowing for an even higher suction temperature, at the same time ensuring no carry-over of liquid to the compressor in a very compact installation. This optimization gives further energy savings of 1.5%.

3. Upgrading the reciprocating compressors to a much more energy efficient compressor

Upgrading to a more efficient reciprocating compressor means less energy consumption per ton of refrigeration. By using a modern compressor compared to a conventional compressor, energy consumption reduces by as much as 20%.

4. Capturing and utilizing the waste heat from condensers for use in seat heating, showers, and Zamboni water heating

In an evaporative or air-cooled condenser, the heat rejected from the condenser is typically wasted to the atmosphere and not recovered. By replacing the condenser with a liquid-cooled plate and frame condenser, instead of wasting the energy, the energy is reused to preheat water for showers, provide space heating, and to preheat Zamboni water to condition the ice sheet.

5. Using a building automation system to control all mechanical equipment holistically

Making great quality ice, cost-effectively, requires all high-efficiency equipment used in ice rinks to operate at peak performance. A fully integrated building automation system that is designed specifically for ice rinks ensures that the facilities are optimized all the time.

Savings and Benefits

Since 2015 the seven completed rink upgrades have reduced consumption by 3,500,000 kWh annually, reducing electricity costs by $600,000 (€529,600) each year.

Canlan calculated that with additional facilities completing upgrades, by the end of 2019, the total electricity consumption was reduced by 10 million kWh annually.

Additional to the energy savings, the following additional benefits were also realized:

Improved safety of the by reducing the ammonia charge of the system significantly.
Using ammonia as the refrigerant, gives much lower GWP compared to fluorocarbon-based refrigerants.
Freed-up valuable space in the engine room by using an Alfa Laval plate heat exchanger with an integrated Alfa Laval U-Turn separator (which has a smaller footprint than the equipment being replaced).
Reduced maintenance and repair costs.

For more information

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Visit: https://www.alfalaval.ca/uturn

CIMCO ECO CHILL ENSURES SAVINGS AND RELIABILITY FOR NHL'S VEGAS GOLDEN KNIGHTS

Operationally, we are saving 20–30% per month compared to synthetic refrigeration systems I have worked with." –Jeremy Brant, Director of Operations, City National Arena

City National Arena is the practice facility and team headquarters of the NHL's Vegas Golden Knights. Opened in 2017, the 146,000ft2 (13,564m2) building is located in Summerlin, Nevada – a suburb of Las Vegas. The facility features everything from sports medicine facilities and a player's lounge to a restaurant and team store.

The facility's two ice rinks, each with 600 seats, are open to all ages and levels, with daily programming 17 hours a day year-round, making it a major hub for recreational and youth hockey in the area. It's also home to the University of Nevada, Las Vegas (UNLV) Rebels hockey program.

Customer Objective

Because of the volume of visitors and standard of ice required, the facility required a reliable system that provides the best ice quality, runs on a sustainable natural refrigerant, and has the lowest operating costs, explains Jeremy Brant, City National Arena's Director of Operations. A system that prioritized energy efficiency was also important.

Using a synthetic refrigeration system was not a viable solution. "In the past, I worked at an arena with a synthetic system – we couldn't rent the second sheet of ice during college games because the system could not keep up, which was a loss of revenue for the building," Brant says.

Cimco's Eco Chill solution checked all the requirement boxes. Brant learned about the Eco Chill's heat recovery technology earlier in his career. He first saw one in action in Lockport, NY, where the facility was using the waste heat from the system to warm the sidewalks, saving the staff time by not having to shovel snow.

The Solution

The facility installed a full Eco Chill package with two Eco Dry units that provide 100% of the dehumidification. The system runs on ammonia refrigerant.

"An ammonia system is there when I need it to perform during the warmest times of the year," says Brant, who also likes the safety aspect of ammonia. "Refrigerants are all dangerous, but with a synthetic refrigerant, if there is a leak, it's odorless, which can put the staff in an unsafe situation. With ammonia, you can smell it, rather than relying on a light or another indicator that may not always work. Because of this, I believe the staff respects the system more."

Reliability

"We have experienced zero issues with the Eco Chill system," says Brant. The arena's air quality is conditioned using the cold and warm glycol from the Eco Dry units, and despite the traffic and demands on the facility, maintaining a professional quality sheet of ice for the Vegas Golden Knights practices isn't ever a problem. "Even with elite players and a high load on the facility during our showcase tournaments, it can hold the ice all day, all year long."

During the facility's first summer in 2018, it reached 115°F (46°C) outside, and City National was hosting a big event. The Eco Chill was able to accommodate the load and maintain a 72°F (22°C) temperature inside the building, while keeping the ice in top condition.

"The ability to tie the HVAC into the ice rink controls is crucial to the building's success," says Brant.

Free Heat

Using waste heat has translated into energy savings for the facility. The waste heat is used for underfloor heating as well as the snow melt pit. Cold glycol from the system is sent to the cold tub for the players' Jacuzzi, while warm glycol is used to air-condition the arena.

Cost Savings

Because refrigeration makes up over 40% of the operating costs of the building, the savings from the Eco Chill system are significant, says Brant. "Operationally, we are saving 20–30% per month compared to synthetic refrigeration systems I have worked with."

The rink requires hot water from 70 to 95°F (21 to 35°C) within the facility, and by preheating the incoming city water with the waste heat from the refrigeration system, they are able to significantly reduce the demand on their natural gas boilers, subsequently also reducing their energy bill.

"The key is to ensure you have the coordination between all the mechanical systems to ensure you maximize the potential savings and efficiency of the system," says Brant. "The decision a facility makes about the refrigeration system should be based on the lifetime, not the upfront cost of the system," he says. "On the surface, the Eco Chill may seem like a lot of money, but getting the savings back within five years on the cost difference is the key."

A Happy Customer

Brant says that the Eco Chill's remote capabilities are a game changer. Because he travels offsite to oversee other facilities, Brant appreciates a system he can monitor remotely. "I am able to see the system at all times, and being able to receive real time notifications is extremely helpful," he says. The team finds the computer program easy to read and very user friendly and considers it an excellent learning tool that provides insights to the overall health of the system. They also appreciate the free training tools for staff who are not knowledgeable with refrigeration. "Having the support of Cimco and the local team has been huge for us."

According to Brant, "The Eco Chill is a popular topic for the Vegas Golden Knights organization because of its consistent performance and the annual operational savings it provides."

For more information

For more information, contact David Fauser at DFauser@toromont.com or visit https://www.cimcorefrigeration.com/.

KEN HOUSTON ARENA REDUCES CARBON FOOTPRINT THANKS TO DOUCETTE

By installing a Doucette waste heat recovery unit, the Ken Houston Memorial Agricultural Centre and Arena reduced its natural gas usage by 20–25%, also realizing additional energy savings.

About the Project

The Ken Houston Memorial Agricultural Centre and Arena (formerly the Lambton-Kent Memorial Centre, renamed after the NHL star) is based in Dresden, Ontario (Canada). In 2012, it started a refurbishment process with the goal of reducing the ice arena's overall carbon footprint.

As such, a project was undertaken to claim excess heat from the refrigeration compressors. This heat was then used to heat water for flooding ice, subsequently reducing the arena's natural gas consumption and related carbon footprint. Previously, no waste heat recovery was done on site.

Savings and Benefits

Over the ammonia/NH_3 (R717) refrigeration system's equipment's lifetime, the potential natural gas savings are significant – 105,000m³ (3,708,040ft3) of gas. This would avoid 170 Mt of CO_2 emissions.

Additional energy savings were achieved in this project by reducing the head pressures, allowing the system to run more efficiently.

The natural gas boiler now only runs when the plant is not operational. The arena has a 350-gal (1,325L) recovery tank to hold the hot water.

"Basically, the boiler never runs in the winter as I am able to heat the 350-gallon water tank for free by capturing the waste heat through the Doucette unit," explained Brad Tuckwell, Supervisor of Recreation Facilities with the Municipality of Chatham Kent Arena; Ken Houston Memorial Agricultural Center, Dresden, Ontario.

A Happy Customer

The customer was very happy with this project and how the system has been running since installation.

"I am very happy with the results," confirmed Tuckwell. "We have, on average, achieved a 20–25% reduction in natural gas by using the Doucette."

For more information

doucette industries, inc.

For more information, contact John Lebo at johnL@doucetteindustries.com or visit www.doucetteindustries.com.

4 Regulations Impacting Ice Rinks in North America

4.1 KIGALI AMENDMENT

The current regulatory landscape in North America has been shaped by the enactment in October 2016 of the Kigali Amendment to the Montreal Protocol, which calls for an 85% global phase down of HFC production and consumption in developed countries by 2036.

Adopted by 197 countries, plus the European Union, the Kigali Amendment is still in the process of being ratified and thereby incorporated into domestic law by the individual countries. Currently, 136 countries, plus the EU have ratified the amendment. If enacted globally, it would avoid up to a 0.4°C (0.7°F) increase in global temperatures by the end of the century, according to UN estimates.

In North America, Mexico and Canada ratified the Kigali Amendment in September and November 2017, respectively. The U.S. Senate is currently considering the amendment, but has not yet taken a vote on it.

Previously, the Montreal Protocol, adopted in 1987, set in motion the phase out of ozone-layer-depleting CFCs and HCFCs globally, though HCFC-22 is still used in some ice rinks.

4.2 COUNTRY REGULATIONS

In Canada, a phase down of HFC production and consumption came into force on April 18, 2018. This phase down began in 2019 with a 10% reduction of the baseline, leading up to an 85% reduction in 2036, in alignment with the Kigali Amendment. HFCs like R134a used in ice rink HFO/HFC blends will be impacted by the phase down.

The scheduled reduction of HFCs includes bans on refrigerants above a certain GWP in specific appliances. In regard to ice rink systems, a chiller (refrigeration or air-conditioning system that has a compressor, an evaporator and a secondary coolant, other than an absorption chiller) will not be allowed to use a refrigerant with a GWP greater than 750 as of January 1, 2025.

In the U.S., the American Innovation and Manufacturing (AIM) Act, enacted in December 2020, gives the U.S Environmental Protection Agency (EPA) the authority to phase down production and consumption of HFCs per the timetable of the Kigali Amendment, as well as ban refrigerants exceeding a specified GWP in certain appliances. The EPA can also facilitate the transition to next-generation technologies, including natural refrigerants.

The EPA has so far published the first of three rules pursuant to the AIM Act. Published in September 2021, this rule creates a quota system based on pre-set yearly maximum allowances, as well as allocation and trading mechanisms. As in Canada, the rule aims to phase down production and consumption of HFCs by 85% by 2036, and affects all companies operating with HFCs, be they producers, importers, exporters, destroyers, users of HFCs as a feedstock, reclaimers, packagers, or distributers. The rule also sets up robust enforcement against illegal trade of fluorinated gases.

The last two impending rules will impose sector-based regulations at the federal level, and detail provisions on reclamation of HFCs from equipment.

Following the publication of the first rule, the U.S. EPA granted multiple petitions from stakeholders on how to regulate HFCs in sectors through the AIM Act. One petition asked the agency to replicate at the federal level the ambitious HFC regulations established by the California Air Resources Board (CARB), including significant sector-based bans.

CARB approved those regulations in December of 2020. The California state level rules and the EU F-gas Regulation are currently considered global “gold-standards” when it comes to phasing down or eliminating HFCs. Washington state has enacted similar rules.

With regard to ice rinks installations, CARB mandates that, as of January 1, 2024, new ice rink facilities use a refrigerant with a GWP of less than 150 and existing facilities use one with a GWP of less than 750.

4.3 SAFETY REGULATIONS

The ice rink sector has safely managed the risks associated with ammonia for decades. Still, there are ammonia safety regulations in the U.S. and Canada that rink owners must follow.

In the U.S., both the EPA and OSHA (Occupational Safety and Health Administration) have programs – the Risk Management Plan (RMP) and Process Safety Management (PSM) – aimed at ensuring the safety of facilities that operate with hazardous chemicals, including ammonia. But both pertain to the use of more than 10,000lbs (4,536kg) of ammonia, which would not apply to ice rinks, which typically use under 2,000 lbs (907kg). However, both agencies require users of less than 10,000lbs of ammonia to adhere to safety protocols under General Duty Clause of the Clean Air Act.

The General Duty Clause requires ice rink owners and operators using ammonia as a refrigerant to take steps to prevent releases, and to minimize the consequences of accidental releases that do occur.

In Canada, the Canadian Centre for Occupational Health and Safety (CCOHS) provides information on the safe handling of ammonia. In addition, provincial authorities enforce safety regulations; for example, the Technical Safety British Columbia (B.C.), oversees the safe installation and operation of ammonia systems. Among other measures, Technical Safety B.C. requires all operators that detect a leak of ammonia to report it to the organization within 24 hours, in accordance with the provincial Safety Standards Act.

Technical Safety B.C. inspects the equipment when it's installed, then does periodic assessments throughout the lifespan of the system.

Other provinces have different inspection regimens: In Saskatchewan and Manitoba rinks are inspected every year. In Ontario, inspections are required every six, 12 or 24 months, depending on the results of the previous inspection.

Canadian provinces also require on-site supervision of ammonia ice rink systems to varying degrees. In British Columbia, arena rinks with systems exceeding 50kW in capacity need to be supervised by a qualified person during rink operation.

Though it is classified as an A1 non-toxic refrigerant, CO_2, like any refrigerant, is capable of displacing air in an enclosed area, and requires CO_2 detectors to warn technicians of a leak. In North America, CO_2 systems, especially the direct version, need to adhere to the ASHRAE-15 safety standard that limits the amount of CO_2 to 3.6lbs/1,000ft^3 (5.7kg/100m^3) of occupied space.

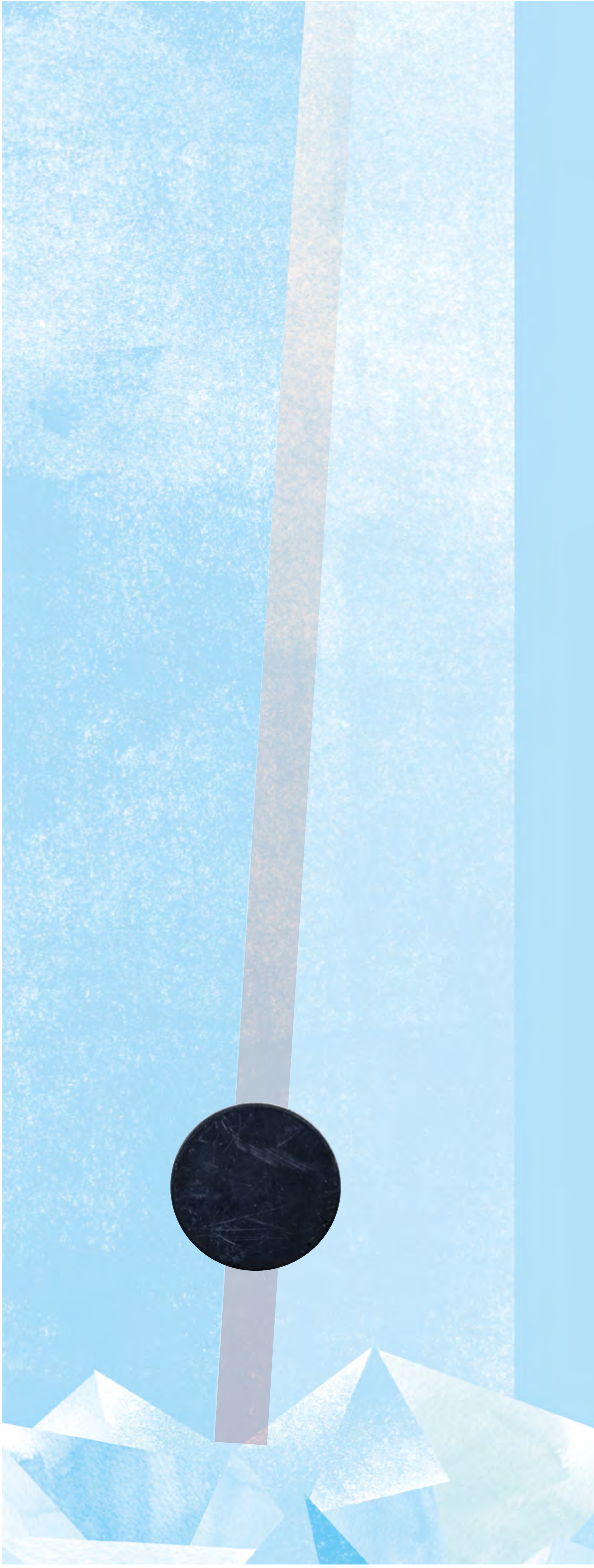
4.4 INCENTIVES

In Canada, government incentives have supported the uptake of natural refrigerants in ice rinks across the country.

In particular the province of Quebec has put in place different public subsidy programs aiming at saving energy and promoting natural refrigerants as a replacement for R22.

For example, the refrigerant incentive – provided by the support program for the replacement or modification of refrigeration systems using either R12 or R22 as refrigerants – would cover up to 50% of the cost incurred by applicants in a transition towards a refrigerant with GWP of less than 10 (up to CA$700,000).

Quebec, through its utility Hydro-Quebec, offers a program to support the energy efficiency of facilities. Even if not strictly related to the use of natural refrigerants, this program could persuade owners of ice rinks to invest in natural refrigerants that demonstrate energy savings.



5 The Environmental and Health Impacts of HFO Blend Refrigerants

5.1 OVERVIEW

Ammonia/NH_3 (R717) has long been used for ice rink refrigeration, and CO_2 (R744) systems are beginning to be used. But in recent years R513A and other HFO blends (R448A and R449A) have been heavily marketed by chemical manufacturers as sustainable ice rink alternatives.

But how sustainable are these blends?

Consider R513A, which has a 100-year GWP of 600 and a 20-year GWP of 1,700, compared to ammonia's GWP of zero and CO_2's GWP of one. R513A owes its high GWP to the fact that it consists of 44% R134a (100-year GWP 1,430), an HFC that is being phased down under the Kigali Amendment to the Montreal Protocol, Environment and Climate Change Canada, and the U.S. Environmental Protection Agency (EPA).

The impact of R513A on global warming can be found in an Environmental Investigation Agency (EIA) exposé on the partnership between Chemours and the NHL. EIA calculated that if all of North America's community ice rinks install R513A instead of ammonia, it would lead to additional CO_2e emissions over the lifetime of those systems that are equivalent to emissions of 15 coal-fired power plants or 13 million cars.

R513A has another environmental impact. It is also made up of 56% HFO-1234yf, which changes, when leaked into the atmosphere, entirely into trifluoroacetic acid (TFA) in only 10–14 days. TFA then descends to Earth in rainfall.

While not currently regulated, TFA is potentially harmful to human health. It is accumulating in the environment, including in fresh water supplies from which it is extremely difficult to remove. The other component of R513A, R134a, also changes to TFA at a rate of 7 to 20%.

TFA, as well as R134a and HFO-1234yf, fall under the definition of PFAS (per- and polyfluoroalkyl substances) established by the OECD (Organisation for Economic Co-operation and Development) and used by scientists around the world. PFAS are a well-known group of chemicals found to be extremely harmful to human health.

In response to concerns about the growth of HFO and TFA levels in the environment, five European countries announced last year their intention to submit a joint proposal to restrict PFAS, including some HFC and HFO refrigerants and TFA, under the EU's REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation. The European Chemicals Agency (ECHA) is expected to take up the proposal next January. The European Fluorocarbons Technical Committee (EFCTC) contends that f-gases should not be regulated as PFAS.

In the U.S., the EPA uses a different definition of PFAS that does not include f-gases or TFA; however, the agency's narrower definition has come under considerable criticism from U.S. scientists; and a bill has been put forward to change the EPA's definition to OECD's.

A fact sheet, "Choosing a Future-Proof Refrigerant for Your Ice Arena" – available here – summarizes the environmental and health issues raised by R513A. It points out that even in the production of R134a and HFO-1234yf, more CO_2e emissions are generated (3.6lbs and 10.9lbs per pound of refrigerant produced, respectively), than are generated by the production of ammonia and CO_2 refrigerant (2.1 and 0.8, respectively).

The fact sheet also provides a timeline of chemical industry statements about CFC and HFC refrigerants that proved to be false over time and were followed by regulatory action.

There are still other concerns related to HFO-1234yf. In order to manufacture it, chemical producers reportedly use carbon tetrachloride (CCl_4), a probable carcinogenic liquid that can damage the liver, kidneys and central nervous system. CCl_4, which evaporates easily, is also a potent ozone-depleting substance, almost as harmful as CFCs, as well as a high-GWP (1,730) gas.

CCl_4 production in the U.S. has been increasing due to its use as a feedstock in the manufacture of HFO-1234yf and HFO-1234ze, according to a 2020 report by Safer Chemicals, Healthy Families' Environmental Health Strategy Center Healthy Building Network. The EPA has reported CCl_4 leaks from facilities operated by Honeywell and Chemours that produce HFO-1234yf.

Yet another issue related to HFO-1234yf has been identified in the automobile industry. In a few instances, HFO-1234yf poured into air-conditioning service units is thought to have previously undergone polymerization, resulting in a silicone-like solid mass that irreparably damages the service unit, according to a report in *Krafthand*, a German technical magazine. Polymerization of the refrigerant would have occurred in its original container as a result of high temperatures (70–90°C/158–194°F) due to exposure to the sun, for example, and the ingress of air.

In stationary refrigerant cycles, "some of the mixtures with R1234yf will polymerize and I think in some plants it has already happened, but nobody had in mind that the 'white residue' may also be related to the refrigerant," said Alexander Türke, a researcher at the Institute for Ventilation and Refrigeration Technology (ILK), in Dresden, Germany. He added that polymerization should only happen in oil-free systems.

The chemical industry addressed the environmental deposition of TFA in an October 2021 study funded by the Global Forum for Advanced Climate Technologies (globalFACT), which represents f-gas producers Chemours, Honeywell, Arkema and Koura (and equipment manufacturer Daikin). The study concluded that "with the current knowledge of the effects of TFA on humans and ecosystems, the projected emissions through 2040 would not be detrimental."

But the study also acknowledged that "the major uncertainty in the knowledge of the TFA concentrations and their spatial distributions is due to uncertainties in the future projected emissions."

A study by Canadian researchers has determined that there are “no compelling scientific arguments” to support the existence of naturally formed TFA, countering a claim about “natural TFA” that is often made by producers of f-gases and referred to in earlier research.

The study, “Insufficient evidence for the existence of natural trifluoroacetic acid,” published on November 1, 2021, in *Environmental Science: Processes & Impacts*, concluded that in the absence of new evidence, “natural TFA should not be invoked in any discussions about the production and/or regulation of TFA.”

A 2017 Norwegian Environment Agency study concluded that nature’s ultimate tolerance to TFA accumulation – and its effect on human health – remain an open question.

Given the persistence of TFA, the risk it presents increases if emissions of HFO-1234yf to the environment grow, the Norwegian report said. With that in mind, it stated that “phasing out HFOs (and consequently TFA), or emission reduction strategies along with best practice measures that help ensure efficient capturing of HFO/TFA during recycling operations, will help reduce the risk to human and environmental health.”

The following is a review of recent studies and developments involving the accumulation of TFA in the environment and its potential impact on human health.

5.2 LEAF SAMPLES FOUND TO HAVE INCREASING AMOUNTS OF TFA

In a study funded by the German Environment Agency (UBA), growing concentrations of trifluoroacetate (TFA) were found in archived leaf samples of various tree species, with a two-to-five-fold increase between 1995 and 2018.

The study attributed the TFA growth to "increasing emissions of gaseous TFA precursors" such as certain HFC and HFO refrigerants.

The study – "Levels and Temporal Trends of Trifluoroacetate (TFA) in Archived Plants: Evidence for Increasing Emissions of Gaseous TFA Precursors over the Last Decades" – was published April 18, 2022, in *Environmental Science & Technology*. Its authors are Finnian Freeling, Marco Scheurer, Jan Koschorreck, Gabriele Hoffmann, Thomas A. Ternes, and Karsten Nödler.

Scheurer and Nödler also participated in another recent German TFA study that found TFA, among other similar chemicals, "widespread and dominant" in 46 water samples collected from 13 different sources of German drinking water.

In its acid form (trifluoroacetic acid), TFA is produced in the atmosphere by the 100% breakdown of HFO-1234yf, and is carried in rainfall to Earth, where it is found in acetate form.

According to the leaf-study authors, this is the first study to describe the "concentrations and temporal trends of TFA in biota by analyzing archived leaf samples of various tree species from the German Environmental Specimen Bank [ESB]." They regard plants as "an efficient biomonitoring tool" to evaluate the presence of TFA in the environment over time.

In total, 55 tree leaf samples from the German ESB were analyzed for TFA. Samples of the same leaf species from different locations each had a similar concentration range of TFA. The highest concentrations (up to about 1,000µg/kg dry weight) were found in Lombardy poplar leaves.

A "statistically significant positive trend" in the TFA concentration within the study period was found for most species and sites. This trend, the study says, is "likely the result of both bioaccumulation as well as increasing emissions of gaseous TFA precursors over the last three decades."

Since TFA was detected in all analyzed plant samples, these results show that "the ubiquitous presence of TFA in dry and wet deposition leads to a widespread contamination of terrestrial ecosystems, even at near-natural and remote locations," says the study.

While the study authors do not know of any "ecotoxicological effect data" for the tree species at higher TFA levels, they see the study results contributing to the "current discussion on the regulation of per- and polyfluoroalkyl substances (PFAS) to protect human and environmental health." TFA is considered an ultra-short-chain PFAS, according to the Organisation for Economic Co-operation and Development (OECD).

The study noted that TFA manifests a very high persistence and mobility in the environment, which means it has "a much higher likelihood for long-lasting and widespread adverse effects." Consequently, the study says, TFA and its precursors "should be considered for regulation to reduce the risk of potentially irreversible harm in the future."

TFA sources include industrial discharges and the degradation of many pesticides and pharmaceuticals. However, the study assumed that the predominant source of TFA in the studied plant matrices was atmospheric deposition from f-gas degradation.

The leaf study encompassed the species European beech, Lombardy poplar, Norway spruce, and Scots pine. The TFA concentrations of investigated tree leaf samples generally ranged from tens to hundreds of µg/kg of dry weight (dw).

5.3 GERMAN STUDY FINDS SIGNIFICANT AMOUNT OF HFO DEGRADATION PRODUCT TFA IN DRINKING WATER

A study funded by the German government has found trifluoroacetate (TFA), a degradation product of certain HFCs and HFOs, "widespread and dominant" in 46 water samples collected from 13 different sources of German drinking water.

The study – "Ultra-Short-Chain PFASs in the Sources of German Drinking Water: Prevalent, Overlooked, Difficult to Remove, and Unregulated" – was published May 4 in *Environmental Science & Technology*. Its authors are Isabelle J. Neuwald, Daniel Hübner, Hanna L. Wiegand, Vassil Valkov, Ulrich Borchers, Karsten Nödler, Marco Scheurer, Sarah E. Hale, Hans Peter H. Arp, and Daniel Zahn.

Funded by Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, the study looked for the presence of short chain and ultra-short-chain PFAS (known as "forever chemicals" for their durability in nature); TFA is considered an ultra-short-chain PFAS, according to the Organisation for Economic Co-operation and Development (OECD). The samples were taken between October 27 and November 4, 2020.

In its acid form (trifluoroacetic acid), TFA is produced in the atmosphere by the 100% breakdown of HFO-1234yf, and is carried in rainfall to the earth, where it is found in acetate form. Between 7% and 20% of HFC-134a breaks down into TFA in the atmosphere.

Short-chain and ultra-short-chain PFAS "generally fulfill" the proposed criteria for persistent, mobile, and toxic (PMT) or very persistent and very mobile (vPvM) substances, established by the German Environment Agency (UBA). Consequently, ultra-short-chain PFAS "represent a major challenge for drinking water production and show that regulation in the form of preventive measures is required to manage them," the study says.

TFA was the most dominant PFAS found in the study, accounting for more than 90% of the total concentration of PFAS analyzed in all samples, with a maximum and median concentration of 12.4 and 0.9 µg/L, respectively. "From the data presented herein, it is evident that short-chain PFASs and especially the ultra-short-chain PFASs TFA, TFMS [trifluoromethanesulfonate], and PFPrA [perfluoropropanoate] are widespread and dominant in these samples from drinking water sources," the study says.

The German Environment Agency has set a "health orientation value" limit of 60 µg/L for TFA and a "precautionary measure" of 10 µg/L.

Denmark has also been studying the presence of TFA in water supplies. In 2021, the Danish Environmental Protection Agency reported finding TFA in 219 out of 247 groundwater wells, as well as in some drinking water supplies. In the vast majority of groundwater wells, the concentration of TFA is lower than 1 µg/L.

The ultra-short-chain PFAS, which were the most prevalent PFAS found in the drinking water sources, are also the ones that are the most difficult to remove during drinking water production, the study says. "This raises questions both about the costs of removing these substances and the potential health effects these chemicals might cause."

The study acknowledged that there is currently little to no data about long-term exposure of ultra-short chain PFAS like TFA. However, "PFASs will remain in the environment for decades once released due to their persistent nature" and "remediation is either unfeasible or exceedingly expensive if adverse effects from these PFASs occur."

The study suggested that the results can be used to "better account for ultra-short-chain PFASs in fresh water and drinking water sources and to support monitoring campaigns, policy development, and risk assessment of these problematic substances."

5.4 IN RAINWATER STUDY, GERMAN ENVIRONMENT AGENCY SAYS HFOS SHOULD BE REPLACED BY NATREFS

In a 259-page 2021 study of the environmental impact of HFOs that analyzed rainwater samples, the German Environment Agency (UBA) concludes that HFOs used as refrigerants, foam blowing agents and aerosol propellants “should be replaced by more sustainable solutions with halogen-free substances” such as natural refrigerants.

The report – “Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential” – focuses on the degradation products of HFOs, notably the conversion of HFO-1234yf into trifluoroacetic acid (TFA) in the atmosphere.

TFA, according to UBA, is “classified as hazardous to water.” Moreover, because of the persistence of TFA in the environment and the difficulty of removing it from groundwater and drinking water, the UBA says in the report that the use of HFOs as substitutes for HFCs “must be regarded as problematic.”

Consequently, the report says, HFO refrigerants, foam blowing agents and aerosol propellants “should be replaced by more sustainable solutions with halogen-free substances.”

“Alternatives with natural refrigerants should be preferred and promoted,” the report adds.

In support of these conclusions, UBA commissioned a two-year measurement of TFA in rainwater, carried out in Germany for the first time, from February 2018 to March 2020, with samples from eight German Meteorological Service measuring stations. The mean monthly TFA precipitation concentrations reached up to 4.87 µg/L. One-year TFA inputs amounted to 190 g/km² in 2018/19 and 276 g/km² in 2019/20, an increase of at least three to four times compared to the period 1995/96 (54 to 69 g/km²).

Based on that data, UBA modeled the “maximal future use and emissions” of HFOs up to 2050. “The projections show that in the future, especially the emissions of the refrigerant [HFO]-1234yf from mobile and stationary air conditioning will add a large additional share to the amounts of TFA or trifluoroacetate in the atmosphere,” the report says.

The model calculation indicates that in 2050 the refrigerant R1234yf alone is expected to cause TFA inputs from precipitation of 2.5 kg/km² per year for Europe and up to 4 kg/km² per year for Germany; this would correspond to a ten-fold increase in today’s TFA inputs, generating up to 50,000 metric tons of TFA load from refrigerant emissions for Europe in 2050.

“If manufacturers and operators now change over to systems using natural substances with a low global warming potential, such as hydrocarbons, carbon dioxide or ammonia, both the emissions of TFA can be significantly reduced and the climate can be protected,” said UBA President Dirk Messner, in a statement.

5.5 CANADIAN RESEARCHERS FIND ELEVATED LEVELS OF HFO-1234YF BYPRODUCT TFA IN ARCTIC ICE

A Canadian study looking at the composition of two Arctic ice cores since 1990 points to the accumulation of trifluoroacetic acid (TFA), an atmospheric byproduct of HFO-1234yf and R134a, which is raising concerns about its long-term effect on the environment and human health.

TFA is one of three short-chain perfluoroalkylcarboxylic acids (scPFCAs) identified in the study – titled "Ice Core Record of Persistent Short-Chain Fluorinated Alkyl Acids: Evidence of the Impact From Global Environmental Regulations" – which was published on April 23, 2020, in *Geophysical Research Letters*. The other two are perfluoropropionic acid (PFPrA), and perfluorobutanoic acid (PFBA).

The study, which determined the content of the ice cores from the Devon Ice Cap in Nunavut, Canada, on a yearly basis, verified that levels of these "persistent compounds" have increased since 1990, following the adoption in 1987 of the Montreal Protocol; that global treaty resulted in ozone-depleting CFC and HCFC gases being replaced by HFCs, and more recently by HFOs.

"We observe the importance of CFC replacements in the increased deposition of TFA," said the study. "Deposition of TFA is expected to increase as new CFC replacement compounds are phased in. This work demonstrates the increased environmental burden of persistent and potentially toxic scPFCAs as a result of global regulation."

Cora Young ,an atmospheric chemist at Toronto, Canada-based York University, and the corresponding author of the study, is quoted by the BBC as saying that the levels of scPFCAs found in the Arctic ice are "on the order of 10 times higher now than we saw before the Montreal Protocol." While the potential toxicity of the compounds is still to be determined, "we do know that we are committing the environment to a great deal of contamination," she added.

In addition to identifying these compounds, the study's researchers, including Young and Amila De Silva, a chemist at Environment and Climate Change Canada, used atmospheric modeling to try to deduce the sources of the compounds, according to an article published May 2 in *Chemical & Engineering News*. The researchers determined that the TFA was a byproduct of HFC-134a and its replacement gas, HFO-1234yf, both used as refrigerants in car air conditioners. HFO-1234yf produces far more TFA than HFC-134a in the atmosphere, with the TFA descending to Earth in rainfall. Young was quoted in the article as saying TFA is "likely circulating throughout the Northern Hemisphere."

On the other hand, the measurements and models showed that the fluoropolymer industry could explain less than 1% of the observed TFA, leaving the CFC replacement compounds as the main culprits. This conclusion was confirmed by examining modeling of the deposition of CFC replacement chemicals, like R134a, which followed the same rapidly increasing trend after 1990.

Looking to the future, Young and her team predict increased levels of TFA from the greater use of HFO-1234yf, which has a much shorter atmospheric lifespan than R134a.

The shorter atmospheric lifespan of R1234yf means that future depositions of TFA will become more localized, close to where it is being used, said Young. However this does not preclude depositions in remote regions, where the concentrations are still expected to double, Young stressed.

5.6 U.K.-LED STUDY PREDICTS SUBSTANTIAL INCREASE IN TFA FROM REPLACEMENT OF HFC-134A BY HFO-1234YF

A study comparing the environmental effects of HFC-134a (R134a) and HFO-1234yf (R1234yf) predicts that the replacement of the former by the latter, such as in mobile air-conditioning (MAC), would lead to substantially more production of trifluoroacetic acid (TFA) in the atmosphere, and ultimately on the surface of the Earth.

The study – "Investigation of the Production of Trifluoroacetic Acid from Two Halocarbons, HFC-134a and HFO-1234yf and Its Fates Using a Global Three-Dimensional Chemical Transport Model" – was conducted largely by researchers at the University of Bristol, U.K., and published in March, 2021, in *ACS Earth and Space Chemistry.*

Because of its high 100-year GWP (1,430), R134a production is being phased down globally under the Kigali Amendment to the Montreal Protocol. It has been widely replaced in MAC applications by R1234yf, which has a 100-year GWP of less than one.

The University of Bristol-led study simulated the effects of switching from R134a to R1234yf and found a 33-fold increase in the "global atmospheric burden of TFA." The amount of TFA would rise from 65 metric tons formed from the 2015 emissions of R134a to about 2,150 metric tons that would be formed in the future from an equivalent emission of R1234yf.

Moreover, in specific geographic areas, the amount of TFA was seen as greater, including an increase of up to 250-fold across Europe and significant increases (up to 50-fold) in regions of the Southern Hemisphere, under the R134a- replacement-by-R1234yf scenario.

Two outside experts weighed in on these findings in a 2021 article. "This is – to our knowledge – the first study predicting such high increases in regional TFA depositions. If the findings can be verified, it would most likely mean the end of widespread use of HFOs," wrote Michael Kauffeld, Professor at the Karlsruhe University of Applied Sciences – Institute of Refrigeration, Air-Conditioning, and Environmental Engineering, and Mihaela Dudita, Project Manager at SPF Institute for Solar Technology, Eastern Switzerland University of Applied Sciences (OST).

The University of Bristol researchers also noted that, while their investigation assumed that future R1234yf consumption would match the peak consumption of R134a seen in 2015, "it is likely that [R1234yf] consumption will increase beyond this point and emissions will grow accordingly." In fact, R1234yf use, they said, is expected to exceed current R134a usage by around 290,000 metric tons per year by 2100.

"This investigation shows that a transition from HFC-134a to HFO-1234yf use will result in a significant overall increase in tropospheric TFA," the study says. "As such, natural cycles of TFA and the proportions that reside in air, land, and sea reservoirs will be altered as environmental contamination increases."

Commenting on TFA's stability in water, Kauffeld and Dudita cited concerns that "any HFO regulation will come into force too late once the negative consequences of an increased amount of TFA in rainwater becomes evident." Already, they said, TFA is "not particularly healthy for some aquatic organisms."

5.7 SCIENTIST URGES U.S. EPA TO BROADEN DEFINITION OF PFAS TO INCLUDE F-GASES, TFA

The definition of PFAS (per- and polyfluoroalkyl substances) used by the U.S. Environmental Protection Agency (EPA) should be broadened to include chemicals such as certain HFC and HFO refrigerants, as well as refrigerant byproduct trifluoroacetic acid (TFA), according to a scientist from the Green Science Policy Institute (GSPI).

The scientist, Lydia Jahl, Science and Policy Associate for GSPI, presented this view via Zoom at a session on the impact of refrigerants on health, safety and climate at the ATMOsphere (ATMO) America Summit 2022. ATMO America, held June 7-8, 2022, in Alexandria, Virginia, was organized by ATMOsphere.

The PFAS category comprises thousands of "forever chemicals" that are toxic, bioaccumulate in humans, animals and plants, and are extremely durable in the environment due to the extremely strong carbon-fluorine chemical bond. They have been employed in hundreds of consumer products, including non-stick cookware, stain repellent, food packaging cosmetics and clothing. The ubiquity of PFAS has led to their being found in drinking water, among other places in the environment.

Because of the difficulty of regulating thousands of individual PFAS chemicals, scientists have urged that PFAS be addressed as a class. However, two differing definitions of this class have emerged.

A definition published last year by the OECD (Organization for Economic Co-operation and Development) describes PFAS as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom. This definition is accepted by "leading PFAS scientists around the world," said Jahl. It is also used by the National Defense Authorization Act (NDAA) and several U.S. states.

By contrast with the OECD definition, the EPA, through its Office of Chemical Safety and Pollution Prevention (OCSPP) defines PFAS more narrowly, saying it contains at least two adjacent carbon atoms, where one carbon is fully fluorinated and the other is at least partially fluorinated.

The OECD's definition of PFAS includes certain f-gases like R134a (an HFC) and R1234yf (an HFO), as well as TFA, which is formed in the atmosphere by the breakdown of 100% of R1234yf and up to 20% of R134a. The EPA definition excludes f-gases and TFA, and many other harmful chemicals.

"HFOs and TFA should be considered PFAS for their shared chemical structure, persistence and potential for harm," said Jahl. "There's no indication that ultra-short-chain [PFAS] molecules are safe. EPA's incomplete PFAS definition leaves room for harm."

Jahl acknowledged that more toxicology data is needed "to be 100% certain" of TFA's potential effect on human health in water supplies and other places where it is collecting. "We need that toxicity data before it would be wise to continue using TFA and products that results in TFA formation."

This is especially true, Jahl added, given the availability of natural refrigerants as "safer alternatives."

5.8 REPORT ON HFO/TFA EFFECTS POINTS TO POTENTIAL HARM TO LIVER AND THYROID FUNCTION

Long-term exposure to HFO byproduct trifluoroacetic acid (TFA) can potentially damage the liver and the thyroid function in humans, according to a report released by Refolution Industriekälte GmbH, a Karlsruhe, Germany-based consulting and engineering firm focused on sustainable refrigeration.

The report – "Report and statement of the downsides of HFO refrigerant usage – Impact of fluorochemical refrigerants and their degradation products on the environment and health" – is available here.

While the report acknowledges that there is no threat of acute TFA toxicity for humans at any of the "current or expected concentrations," it says that "long-term exposure [to] low concentrations [of TFA] showed elevated ALT [alanine transaminase]-concentrations [in people] and indicate[s] that TFA in drinking water can potentially damage the liver and have other impacts, for example on the hormone system," in particular thyroid function.

An elevated blood level of ALT, an enzyme, is an indication of liver damage. In regard to the thyroid, the report notes that, while there is a lack of information in the literature regarding the general effect of fluorochemical refrigerants on the thyroid, "it is known that halogen molecules influence the thyroid function. Therefore, HFO and TFA might also have the possibility to cause hypothyroidism and other consequences such as [on] the brain development of children due to iodine deficiency during pregnancy."

The report describes "a long-time toxicity assessment of TFA," citing Umweltbundesamt (the German Environment Agency), 2020, which was performed after "concerning reports of high TFA concentrations in waters in North Rhine-Westphalia, Germany."

In this study, rats were exposed for one year to TFA concentrations of 0 ppm, 30 ppm, 120 ppm and 600 ppm in fresh water. "The study showed an increase of the ALT concentration, depending on the dosage of TFA," the report says.

TFA's impact on the environment is "well established" with regard to freshwater green alga (selenastrum capricornutum, which is the most sensitive algae to TFA in the aquatic environment, the report notes. The report acknowledged that in other environmental impacts, the current and expected concentrations of TFA are lower than the concentrations known to have a negative effect.

However, it notes, "exact concentrations are difficult to predict and concentrations might be higher than estimated by global atmosphere models in the future."

The report's overarching message was a warning to the HVAC&R industry: "Before bringing tonnes of chemicals into the environment, it needs to be proven that they are harmless to human and the environment, especially regarding chemicals with high persistence such as TFA."

If this warning goes unheeded, the report says, "It is no question that sooner or later negative effects or an environmental disaster will happen; it is only a question of when it will happen."

Indeed, history has already demonstrated that emitting chemicals or substances in large quantities into the environment without knowing their exact impacts "can result in global threats that prevail over generations and require regulations to avoid further damage," the report says.

Taking this risk is unnecessary, the report notes, given that natural refrigerant alternatives are widely available for a myriad of applications. "We demand to immediately stop the selling of synthetic refrigerants and switch to naturals only," says the report.

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